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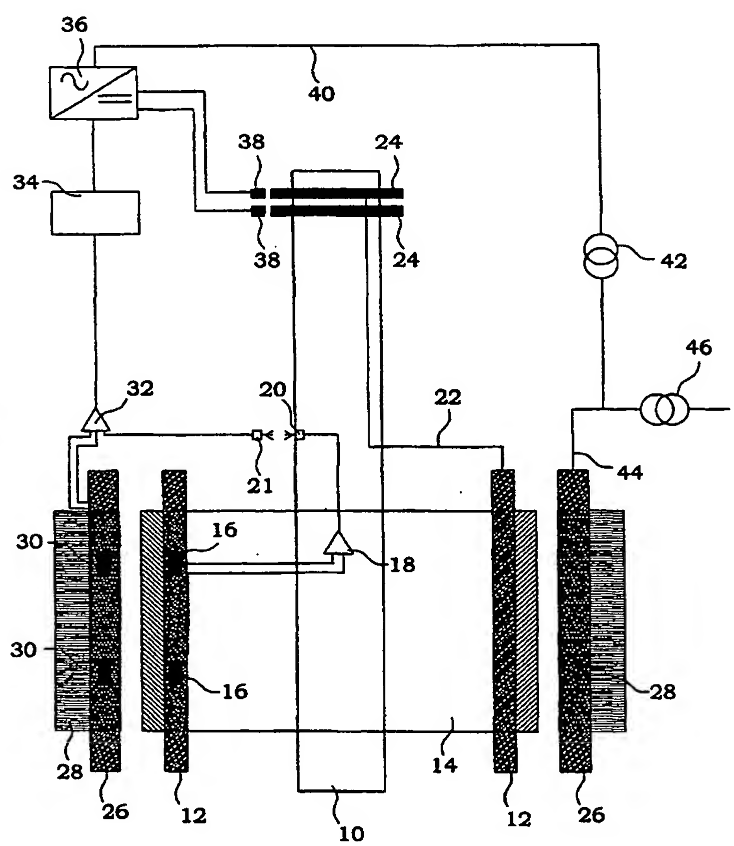

(57) Abstract: In the present invention is the temperature for rotor winding (12) measured in an alternating current machine with rotor windings (12) during operation. The measured temperature is then used to, in a controlled manner, utilise the margin in thermal material utilisation that the insulation material in alternating current machines in general has. Rotor and/or stator current can be regulated in order to give rise to a required production or consumption of active and reactive power. The currents can be allowed to exceed nominal values during a limited time, as a result of the temperature monitoring. The principle of the monitoring may also be utilised in order to give a better protection against overload. An electric power network with connected alternating current machines of this kind may at operation problems utilise existing temperature margins during shorter times in order to facilitate the continuous operation of the electrical power network. The information about the margins of the different machines may be pre-stored for an easy co-ordination of measures when faults appear.

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 98/34312 A1 (ASEA BROWN BOVERI AB), 6 August 1998 (06.08.98), page 5, line 14 - line 25; page 7, line 27 - page 8, line 15	1-15,27-41, 52-59

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MATERIAL-UTILISED ALTERNATING CURRENT MACHINES

TECHNICAL FIELD

The present invention relates generally to devices and methods for control of alternating current machines. The invention relates in particular to control of the power conversion in synchronous and asynchronous machines having solid insulated rotor windings by changing power production or extraction during monitoring of the rotor winding temperature of the machine. The invention also refers to electric power plants comprising controllable alternating current machines, and control of such plants.

BACKGROUND

An electric power network consists in principle of a number of sources and sinks for electrical power. Many sinks, such as bulbs etc. have a more or less pure resistive impedance and give rise to a consumption of essentially only active power. Other loading objects, such as induction motors have on the other hand an impedance with an inductive component and consume thereby both active and reactive power. The electric power network thus has to provide a certain flexibility and capability to deliver or receive power, in particular reactive power. Alternating current machines that work as electric generators in an electric power network deliver both active and reactive power to the power network, in an extent that is determined by the supplied mechanical power, and by the magnetisation of the machine. By changing these operation conditions, the relation between transmitted reactive and active power is changed. Alternating current machines that operate as motors, such as synchronous motors, receive active power from the electric power network and deliver normally reactive power to the electric power network. The exception is asynchronous motors with short-circuited rotor, which always have to be supplied with reactive power, often by phase compensation by using shunt capacitors. Generally, an alternating current

machine thus constitutes a converter for active power and at the same time a simple and easily available adjusting device for reactive power.

Transmission of both reactive and active power contributes to power losses in electric power networks. Furthermore, shortage of reactive power or an unfavourable distribution of it in an electric power plant or an electric power network may lead to so-called voltage collapse. This is particularly important in connection with the occurrence of larger faults in the power network, e.g. when larger generators or motors suddenly fall out. When this happens, the properties of the electric power network change. Different regulators in the electric power network or the electric power plant will try to maintain the frequency and the voltage within the predetermined limits. This may today among other things be performed by changing active and reactive production at generators and by changing the transformation ratio by online tap changer regulation in transformers. However, this has at certain occasions proved not to be enough. If the need of reactive power is larger than what the electric power network can provide, the transmission capability in the electric power network may break down very rapidly in that the maximum point at the so-called PV-curve is passed or in that there are further disconnections of remaining production units as a result of overload. The limitation of the amount of transmitted power depends in many electric power networks on shortage of reactive power, mainly at critical points in the network and not on that thermal limits of transmission lines are exceeded. It is thus of great importance for an electric power network operator in order to be able to control the voltage of the electric power network, to maintain a suitable distribution of sources and sinks of reactive power, and to be able to change this distribution during shorter periods.

One way to control the reactive power is the introduction of phase compensating elements in the electric power network. For large and complex networks, in particular if the nature of the load changes from one period of time to another, such solutions require extensive analyses and simulations in order to determine, in an optimum way, positioning and electric power for

these phase compensators. Furthermore, procedures for how these are to be controlled for different operational conditions in the network are required. Another measure in order to control the amount of reactive power may be to change the operational conditions for alternating current machines, in order to make these reducing or increasing delivered or consumed reactive power. Since many alternating current machines, both in generator operation and in motor operation, operate close to their nominal powers, the margins for such changes are, however, normally very small. In order to be able to influence the relation between reactive and active power in a significant way, also the active power of the machine has typically to be decreased, in order for the magnetising or winding temperature not to exceed their nominal values. A phase compensation via alternating current motors is therefore normally only possible to occur by decreasing the active power, which in most cases is unsatisfactory.

Alternating current machines according to the state of the art are normally provided with different kinds of overload protections and/or limiting devices. The limits for how hard an alternating current machine can be utilised are often set by considerations regarding temperatures, e.g. the temperatures of the stator and rotor windings. Allowed currents in the windings are generally estimated by means of simple theoretical models. For the rotor winding, a limit for the current is typically set by the magnetising equipment. This may have a limit at e.g. nominal rotor current. Larger machines are often equipped with a rotor current limiter, which besides a momentary limiter may contain a time-delay that allows a certain over-current during a shorter period of time. This limitation is, however, static and does not take the actual thermal condition of the synchronous machine into account.

In the patent US 4,114,077 a rotor overtemperature protection device is disclosed. The aim of the protection is to prohibit the non-insulated squirrel-cage of the rotor to thermally expand causing mechanical damage of the rotor or get into mechanical contact with the stator. This is a typical example of the above described protection devices. If a temperature threshold is

exceeded, the protection device gives a signal and the overall operation of the machine is interrupted. The sensor is not a temperature meter; it only gives a signal at a critical value. This corresponds vary well to the failure it is a protection against, i.e. thermal expansion of rotor squirrel-cage windings. For solid winding insulation the temperature limit is influenced also by the time, and hence flexible temperature limits are possible to define. This necessitated for more sophisticated temperature meters.

In the patent application EP 0 902 265 a temperature supervision device is disclosed. A temperature sensor senses the temperature of the rotor itself, and the reading is transferred to the static side. The device is preferably used in a turbopump, and a too high pumping pressure may increase the rotor temperature such that the thermal expansion exceeds the mechanical tolerances in the pump, which will result in damages of the pump. The monitored temperature can be used for changing the operation of the motor in order to protect it from such high rotor temperatures, e.g. by reducing the rotational speed. This is also a typical example of a pure protectional device.

The stator winding on alternating current machines are normally protected by an over-current protection. At overload of the machine, such as that the current exceeds a limit given by nominal power, the machine is disconnected. Synchronous machines may be equipped with a stator current limiter. One is then able to regulate down the rotor current in order to limit the reactive power so that the operational point is kept within the allowed operational area in a well-known "P-Q circle diagram", which for the skilled man in the art often is called capability diagram. This is also performed independent of the actual temperature of the stator winding.

In the US patent 5,321,308 a control apparatus for turbine generators is disclosed. The apparatus protects stator and rotor from over-temperatures by monitoring temperatures of stator and rotor. The rotor temperature measured indirectly, i.e. calculated from rotor currents and rotor voltages, which means that only the average rotor temperature is monitored. Model

based maximum over-excitations are applied, which are not dependent on the measured temperatures. This apparatus is a good example of a combination of limiter and protection device.

Alternating current machines with a power over 5 MVA are today equipped with resistive temperature sensors (e.g. Pt100 elements) which are placed in or in close connection to the stator winding. These give a good information about the working temperature of the winding. These are connected to a protection that disconnects the machine when the temperature reaches over a certain limit. These limits are typically established from the temperature class or from measurements during starting-up of the machine.

In the patent SE 510 315, a special application of an alternating current machine is disclosed. The machine has a stator winding of insulated high voltage cable. Due to the inherent properties of these machines, the rotor windings may in turn be designed in a way that it always is the stator current that acts limiting on the utilisation of the machine. The rotor temperature is therefore of no interest. The control of the machine thus depends solely on the stator current and stator temperature. The findings from this patent is obviously not applicable to a general alternating current machine, where the thermal stress caused by the rotor current plays an important role for an optimum design for the whole machine.

A problem with machine protections and limiters according to prior art is that they in many cases are based on rough static models about loss generation and conduction and temperature rise. The actual conditions, such as variation in the temperature of the environment, are generally very little taken into consideration. In order to obtain a protection also for rather extreme conditions, large security margins have to be used. In less extreme cases, this leads to that the protections are released unnecessarily early in a process. Furthermore, if a load drop or fault in the electric power network causes an unfavourable division of reactive and active power, this may easily lead to a temperature and/or current increase in certain parts of an

alternating current machine. If the protection is set to a completely too low level, such an electric power network situation may lead to that the protection of the machine is activated and that the machine thereby is turned off. This may in turn lead to an aggravated condition for the electric power network.

SUMMARY

A general object of the present invention is thus to provide methods and devices for alternating current machines, with which one increases the possibilities and flexibility to temporarily change consumed or supplied active or reactive power to an electric power network. Another object is to provide electric alternating current machines that have larger margins for changes of its operational state. A further object of the present invention is that in the long run provide a power network with increased possibilities to planned and/or coordinated power alterations.

The above objects are achieved by methods and devices according to the enclosed patent claims. In general words, the temperature of the rotor winding and/or its insulation is measured during operation. The measured temperature is then used to utilise, in a controlled manner, the margin in thermal material utilisation that the isolation material in alternating current machines in general have. Rotor and/or stator current may be regulated in order to give rise to a requested production or consumption of active and reactive power. Even if the regulation of the currents and temperatures of the windings are made to exceed nominal values, one may with the temperature monitoring deliberately allow this during a limited time period, possibly at the expense of the life of the material. An electric power network with alternating current machines of this kind may utilise existent temperature margins in connected machines, and at operational problems, these margins may during a shorter time be taken advantage of in order to facilitate the continuous operation of the electric power network. If the information about the margins of the different machines are pre-stored,

measures to be taken at different kinds of operational problems may be pre-planned and a co-ordination of measures may then be taken when faults appear.

The present invention is particularly suitable to be used for generators and large motors with a power over about 10 MVA. It is also particularly suitable to be used for machines with conventional stator voltage at connection to the electric power network, i.e. for voltages below 25 kV.

SHORT DESCRIPTION OF THE DRAWINGS

The invention and further objects and advantages that are achieved thereby are best understood by reference to the description below and the enclose drawings, in which:

Fig. 1a is an equivalent scheme for a synchronous machine when the resistance in the stator winding is neglected;

Fig. 1b is a combined capability and phasor diagram for a synchronous machine in over-magnetised generator operation;

Fig. 2a is a schematic drawing of how the current may be increased in a stator or rotor winding, when the temperature margins are utilised;

Fig. 2b shows a typical relation between life and temperature of an isolation material;

Fig. 3 shows the change in the operational state of a synchronous generator when it is overloaded with reactive power;

Fig. 4a shows a time course for the temperature of the rotor winding when a synchronous generator is overloaded with reactive power in two intervals;

Fig. 4b shows a time course for the temperature of the stator winding when a synchronous generator is overloaded with reactive power in two intervals;

Fig. 5a shows a controlled time course for the rotor current in order to regulate reactive power and temperature in the synchronous generator at reactive overload;

Fig. 5b shows the time course for reactive power production when the synchronous generator is overloaded according to Fig. 5a;

Fig. 6a shows a reformulated equivalence scheme for an asynchronous machine with winded rotor;

Fig. 6b shows the change in the operational state of an asynchronous machine in generator operation when it is overloaded with active power;

Fig. 7a shows a time course for active power production when an asynchronous machine in generator operation is overloaded by active power in an interval;

Fig. 7b shows a time course for the temperature of the stator winding when an asynchronous machine in generator operation is overloaded with active power in an interval;

Fig. 8 shows the change in the operational state of a synchronous motor when it during a short time is overloaded with a reactive power that is not permitted for continuous operation;

Fig. 9a shows a time course for reactive power production when a synchronous motor is overloaded with a with time varying reactive power;

Fig. 9b shows a time course for the temperature of the rotor winding when a synchronous motor is overloaded with a with time varying reactive power;

Fig. 10 shows a block diagram of a synchronous machine according to the present invention with static magnetisation;

Fig. 11 shows a block diagram of a synchronous machine according to the present invention with brushless magnetising;

Fig. 12 shows a block diagram of an asynchronous machine according to the present invention with winded rotor and slip rings;

Fig. 13 shows a block diagram of a control system for an alternating current machine according to the present invention;

Fig. 14a shows a block diagram of an electric power plant with two alternating current machines according to the present invention;

Fig. 14b shows a block diagram of communicating electric power plants;

Fig. 15 shows a flow diagram of a control method for an alternating current machine according to the present invention;

Fig. 16 shows a flow diagram of a protection method for an alternating current machine according to the present invention; and

Fig. 17 shows a flow diagram of a control method for an electric power plant according to the present invention.

DETAILED DESCRIPTION

Alternating current machines may be used under different operational conditions, whereby they give away or take up different active and reactive power. In fig. 1a, an equivalence scheme for a synchronous machine in stationary operation is shown. In this case, the difference in reactance between the direct and the quadrature axis is disregarded, i.e. one assumes that one has a round rotor. A machine with pronounced poles does not have any corresponding scheme, but the basic principles of the present invention nevertheless apply also for such machines. I_A denotes the stator current and jXs denotes the synchronous reactance 2. A pole voltage Us is applied over the connection terminals and an inner excitation voltage E_A, which is controlled by the rotor current I_F, is created in a fundamental voltage generator 1.

In figure 1b, a corresponding capability diagram is shown. P denotes the active power and Q the reactive power. In figure 1b, one has assumed that the pole voltage amounts to its rated value Us. The current in the windings has specified rated values I_{FN} and I_{AN}, which should not be exceeded. These rated values I_{FN} and I_{AN} are represented in fig. 1b by the circle arcs 6 and 7, respectively. Permitted operational conditions are thus limited to an area where both $I_F \leq I_{FN}$ and $I_A \leq I_{AN}$. This means that the area 3 is not permitted

since I_A is limiting and the area 4 is not permitted since I_F is limiting. According to IEC 34-1, sect. 9, a synchronous generator is marked with rated apparent power S_N and its rated power factor cos ϕ_N. From these data, active and reactive rated power can be calculated (P_N and Q_N, resp.). Corresponding reasoning can be performed for synchronous motors. Any possible control of the operational conditions of the machine is thus limited to an area 5. An operational state is given by the powers P_1 and Q_1, which are positioned within area 5.

A change of the pole voltage Us to the machine changes the capability diagram, which also concerns the efficiency of the method, but not the principle of the method. Since the rotational speed of the machine is assumed to be constant, the ventilation and friction losses are normally likewise constant. Even if the pole voltage Us may vary, this influences very little on the magnetisation losses in the machine. The machine is then limited as indicated in fig. 1b by the rated values I_{AN} and I_{FN} of the stator and rotor currents, respectively.

If the machine operates at rated power P_N and Q_N, one quickly realises that an increase in the reactive power Q can not be performed without exceeding the rated currents I_{AN} or I_{FN}. The only way to increase the reactive power Q is to simultaneously decrease the active power P, which in most cases is not adequate. The margins within which the active and reactive power is allowed to be varied is in practice very limited in this view.

The temperature in the windings of the rotor in an alternating current machine is thus, as discussed above, often a limiting parameter for the capacity of the alternating current machine to produce electric momentum as well as its capacity to produce reactive power via the stator windings to the power network. Limits for temperatures and currents are set in order to protect the machine against destroying overloading. However, existent alternating current machines often have a large thermal margin in that the designer built in security margins at the design of the machine or in that

new experience values have been achieved since the machine was taken into operation.

In the following, a description is given of the thermal utilisation of the rotor winding insulation and what margins that normally are available in a large alternating current machine and that can be utilised by the present invention.

The insulation in alternating current machines with conventional insulation is divided into temperature classes that states how high temperature that is permitted. For rotating machines, these are described in IEC publication 34-1 "Rotating electrical machines", sect. 7, "Thermal performance and tests". Furthermore, for large machines there are often own customer specifications, which puts additional demands on the temperature in the winding insulation in different operational modes. Maximum temperature in the winding insulation in a stator for the different classes is given in table 1. Similar classification is available also for rotor winding insulation.

Klass	Maximal temperatur	Temperaturskillnad till kylmedium
A	105°C	65°C
B	130°C	90°C
F	155°C	115°C
H	180°C	140°C

Table 1. Isolation classes for indirect air-cooled rotating machines when the temperature is measured by a thermometer. Maximum allowed temperature varies somewhat with measuring method.

For air-cooled electric generators, it is normally a demand of that the machine should be able to operate with a temperature on the cold cooling air of up to 40°C. The machine should then be dimensioned based on a temperature increase from this. The same is essentially valid for large

industrial motors. In the last column in table 1, the temperature difference to the cooling medium with maximum temperature that should be used at calculations is shown. The real temperature on the cold cooling air is in many cases colder. A machine with open ventilation uses the air in its environment for cooling, or it may perhaps have an air inlet for the cooling air. This normally means that the temperature of this air, at least during certain periods of the day or year, is much colder. One may thus allow for an increased temperature rise in the machine without exceeding the absolute limit values in table 1. For machines with closed ventilation, the water temperature to the air cooler will in similar manner vary during the year or day. The same will be valid for machines with direct water cooling, i.e. where water is led into conducting conductors and/or laminated parts of the machine.

For large alternating current machines that are built in small series, for the reason of uncertainty in the dimensioning basis, one wants to dimension the machine for to operate with a temperature that is somewhat below the specified temperature. This is attributed to the costs, which are connected to re-design and reconstruction if the temperature limit is exceeded.

For certain machines, such as large electric generators and motors, the customer wants that the machine should be constructed for one temperature class lower than what the insulation endures, e.g. that the machine is made with windings for class F, while it is utilised thermally according to class B. This is for to have an extra safety at temporary faults and in order to be able to handle increased long time effects, which where unknown at the time when the machine was delivered and put into operation.

For electric generators, the price is partly determined based on the efficiency of the machine. For a supplier, it is therefore important to optimise the machine regarding losses. It may therefore at certain occasions be economically optimal to make a machine that is utilised such that the losses

are reduced. This normally leads to that the machines becomes colder than what is permitted according to the temperature classes.

The specified temperatures for each temperature class are valid for continuous operation. For intermittent operation, one may with a short duration allow higher temperature without destroying the insulation. For organic insulation, one normally calculates with that the life is halved for each 8-12°C that the operational temperature is increased. This is illustrated in fig. 2b. For an increase of the operational temperature of ΔT, the life is reduced from t_0 to t_1. This may also be expressed as

$$t_1 = t_0 \cdot e^{-\left(\ln 2 \Delta T / \tau\right)},$$

where τ amounts to the value 8-12°C. One may thus during shorter periods of time, e.g. during 30 minutes or an hour, increase the temperature above the maximum temperatures in table 1 without to any appreciable extent shortening the total life of the insulation.

By this, one realises that by taking standards, customer requests, uncertainty in dimensioning and inherent tolerances in insulation margins, there exists in large electric generators and motors today a significant thermal capacity, which temporarily may be utilised in order to increase the power of the machine. This is illustrated in fig. 2a. The diagram shows a number of current levels I_0 to I_4. I_0 corresponds to the calculated rated current, with considerations taken to temperature class, maximum cooling medium temperature and dimensioning margins, i.e. the normally specified maximum current. If direct measuring of the temperature is performed, one does not need to utilise any dimensioning margins and a current I_1 can be used without any risk for damages. If furthermore a cooling medium with a lower temperature than 40°C is used, the current may be increased further I2 without exceeding the requested temperature of the insulation. If additionally the actual temperature durability of the material is used, instead of the maximum temperature for the temperature class of the

insulation, there is an additional margin to utilise and a current I_3 can be used. This current may thus be used at continuous operation without ageing the insulation more rapidly than calculated. For shorter time periods, the current may be increased further, to a value I_4, when a deliberate power increase is exchanged to a faster ageing of the insulation material. The value I_4 should, however, be kept below an absolute maximum level, over which the risk for material damages within a short time is considered to be too large.

There are today a large number of alternating current machines installed in power plants, which were built several decades ago and which gradually undergo restorations. The evolution of the insulation materials has during the years lead to possibilities to, in existing slots, having space for more copper and/or for more current in the windings since the voltage strength and/or temperature class has increased.

In connection with restorations of an existing alternating current machine, one will therefore be able to increase the rated power on the machine. This is sometimes taken out as increased active power by rebuilding turbines and other mechanical arrangements. It may also be taken out as increased reactive power, whereby in particular the capability of the rotor winding/field winding to bear current is required. Restorated machines thus constitute excellent object for to apply the present invention on.

Further discussions about rotor temperatures may be found e.g. in "Rotor heating as an indicator of system voltage instability", IEEE Trans. on Power Systems, Vol. 10, No. 1, Feb. 1995, pp. 175-81.

Some examples on situations where alternating current machines can be overloaded will now be described, in order to elucidate the possibilities for temporary changes of the power conversion in an alternating current machine.

First, it is described how an alternating current machine may be overloaded with reactive power when it operates as generator. In figure 3, it is shown how the continuous operational state of the machine is altered when reactive power production is increased from Q_2 to Q_3 for a synchronous machine with maintained active power production P_2. The temporary limitations for stationary operation, which the machine has when the insulation is used thermally, are shown by the circle arcs 8 and 9. These limitations 8, 9 can be estimated from the continuous or intermittent temperature measurements. Since the measurements are updated as time goes, also the limitations can be updated with time, e.g. if unexpected outer effects supervene, such as a considerably enhanced cooling water temperature. The total power may thus without risk for damages on the insulation be put outside the area 5, which was not possible within prior art. In this respect, it is possible to still deliver the same active power to the electric power network, despite that an increased reactive power extraction takes place. The increased reactive power extraction will result in an increased temperature in the rotor and stator windings, but this temperature increase is carefully monitored and may thus not lead to undesired material damages. In the shown case where the reactive power Q3 is extracted, the continuous operation is limited by the rotor current.

Figure 4a and 4b show how the temperature in the windings of the rotor and stator, respectively, is increased during a period when the machine delivers extra reactive power. ϑ_N specifies nominal temperature for the respective windings, ϑ_M specifies maximum temperature for shorter overloads for respective windings, ϑ_B specifies starting temperature for respective winding before the increased power extraction and ϑ_E specifies the temperature at a stationary state during increased power extraction. The figure presents three time intervals. The first corresponds to continuous operation. The time interval Δt_1 corresponds to a temperature increase phase and the time interval Δt_2 corresponds to a stationary phase at enhanced temperature. The intervals are described more below.

The rotor current is regulated according to a curve, which is shown in figure 5a, whereby a reactive power extraction according to fig. 5b is accomplished. The rotor current is increased in the interval Δt_1 to a temporary value I_T, somewhat over the permitted one for static conditions. The achieved reactive power then follows a similar curve, according to fig. 5b. The temperature of the windings of the stator and rotor, respectively, will then gradually increase according to conventional heat conducting principles. When the maximum temperature for either stator or rotor has been reached, the rotor current is reduced to a value I_{E2}, which is adjusted in order to maintain the temperatures constant at this higher level. This interval is specified by Δt_2. In this case it is the rotor windings that first reach maximum temperature and which therefore act limiting, according to fig. 3.

Thus, when the monitoring system, which is made possible by the continuous or intermittent temperature measurement, shows that the rotor winding temperature ϑ_R has reached its maximum value ϑ_M, the rotor current I_R is regulated down again to a value I_{F2}, which keeps the rotor winding at a steady high temperature in the vicinity of the maximum ϑ_M. The reactive power Q amounts during the interval Δt_2 to a value which exceeds the nominal ϑ_N. This utilisation of the temperature margins in the machine leads to that the life of the insulation material may be shortened. Δt_2 should therefore be limited in time, whereupon the rotor current I_R is decreased again in order to let the temperature return to a level below the nominal ϑ_N. The duration of the interval Δt_2 may typically be from 10-15 minutes up to some hour, or until the temporary need for reactive power is reduced or disappears.

The temporary limitations of rotor and stator current that are shown in fig. 3 concern stationary or semi-stationary conditions. During the transient phase deltat1, where the temperatures are regulated up, the currents may be increased further, since the machine then is not in thermal equilibrium. This is not shown in the diagram of fig. 3, but it is obvious for anyone skilled in the art that such a further increase according to fig. 5a can occur.

Figure 6a, shows a reformulated equivalence scheme for an asynchronous machine with winded rotor where X_M is the magnetising reactance, while X_{LS} denotes the leak reactance in the stator winding. The sum of these constitutes the reactance of the stator winding and is denoted by X_A. The value and phase of the rotor current I_R are referred to the stator side of the machine. One should note that unlike the equivalence scheme in figure 1a, fig. 6a is valid also when the rotor rotates asynchronously.

In figure 6b, it is shown how the continuous operational state of an asynchronous machine is changed when active power production is increased from P4 to P5. The temporary limitations that the machine has when the insulation is utilised thermally are shown with the circle arcs 8 and 9. These limitations 8, 9 may as above be estimated from the continuous or intermittent temperature measurements. The total power may thus also here without risk for damages on the insulation be put outside the area 5, which was not possible within the prior art. In this respect, it is possible to increase the delivery of active power to the electric power network. The increased active power extraction will result in an increased temperature in the windings of the rotor and stator, but this temperature increase is carefully monitored and may thus not lead to undesired material damages.

A time course for a controlled overload is shown in the figures 7a and 7b. By controlling the root means square (RMS) value of the rotor current according to fig. 6b, an increased active power can be obtained during a time interval Δt_3, as shown in fig. 7a. This active power corresponds in this example to the estimated power that during stationary operation gives a maximum temperature of the stator. After the time interval Δt_3, the power is regulated down back to the normal. In fig. 7b, the temperature response in the stator winding is shown. During the interval Δt_3 the temperature increases gradually towards the expected end value ϑ_M, but does not reach all way up before the time interval is over. The stator temperature is thus in other words all the time kept within allowed temperature values.

In figure 8, it is shown how the continuous operational state of the synchronous machine is changed when reactive power production temporarily is changed from Q_6 to Q_7 in motor operation. The temporary limitations for stationary operation that the machine has when the insulation is utilised thermally are shown with the circle arcs 8 and 9. The limitations 8, 9 may as above be estimated from the continuous or intermittent temperature measurements. The total power may thus also here without risk for damages on the insulation be put outside the area 5, which was not possible in prior art. The operational point may even, as in this case, during a limited time be placed outside the limitations 8 and 9, thanks to a continuous or intermittent temperature monitoring. In this respect, it is possible to increase the delivery of reactive power to the electric power network. The increased reactive power extraction will result in an increased temperature in the rotor and stator windings, but this temperature increase is carefully monitored and may thus not lead to undesired material damages.

A time course for a controlled overload is shown in the figures 9a and 9b. By controlling the rotor current according to fig. 8, an increased reactive power may be obtained during two time intervals Δt_4 and Δt_5, as shown in fig. 9a. During the time interval Δt_4, the extraction of reactive power is regulated up to a very high level Q_7, which gives a very fast temperature rise in the rotor, as shown in fig. 9b. This may e.g. correspond to an emergency situation where the electric power network is risking collapse as a result of shortage of reactive power. When the rotor is coming closer to its maximum temperature ϑ_M, the reactive power Q has to be limited, in order for acute damages not to arise at the rotor. The reactive power is therefore regulated down gradually during the time interval Δt_5, when the electric power network hopefully has managed to recover or when any other machine takes over the production of reactive power. In figure 9b, the temperature response in the rotor winding is shown. During the interval Δt_4 the temperature rises strongly, but when the reactive power is regulated down, the temperature starts eventually to fall to return to a normal value. The rotor temperature is with other words all the

time kept within the allowed temperature values despite a very strong temporary load.

The time course when the power to the alternating current machine is temporarily increased may be varied in relation to the earlier description. In a general embodiment the extracted power may be varied arbitrarily, under the condition that the measured or estimated temperature is kept under control.

It is furthermore obvious that a combination of regulation of active and reactive power can be performed. One may thus e.g. reduce the active power in order to be able to increase the reactive power further. It is also possible to keep the relation between active and reactive power, but only to increase the total power exchange.

The method may thus be used in principle for to increase or decrease active or reactive power for synchronous or asynchronous machines in motor or generator operation. Anyone skilled in the art however realises that certain of the cases leads to unfavourable operational conditions for the machines and are of less practical importance, even if it in principle is possible. The most usable case is judged to be reactive overload of an electric generator.

The present invention, which uses thermal material utilisation of an alternating current machine, can be utilised by different types of instrumentation for measuring or estimating the temperature of the insulation of the rotor winding. The controlled time course of the increased power conversion may be varied in different ways according to the basic idea that the present invention mediates.

The present invention assumes that one during operation knows the temperature for the rotor winding or its insulation with a sufficiently accuracy and time resolution. The temperature of the insulation in the rotor

winding can be determined in different ways depending on the accuracy that is required.

Fig. 10 illustrates a sketch of how the method can be utilised for a synchronous machine with static magnetising. A rotor 14, arranged around a rotating shaft 10, is provided with windings 12. The rotor rotates within a stator 28 with stator windings 26. A power transformer 46 supplies the stator windings 26 with current through wires 40. The direct current from the alternating to direct current (AC to DC) converter 36 is brought over brushes 38 to slip rings 24 arranged at the rotor shaft 10 and further to the rotor windings 12 via wires 22. This constitutes in principle a synchronous machine with static magnetisation according to prior art. According to the present invention, the temperature in the rotor winding is measured continuously or intermittent. The temperature in the rotor winding is determined in the presented embodiment directly by measurement during operation. This is accomplished by placing one or several sensors in the winding or winding insulation ("Embedded Temperature Detector", ETD). The rotor temperature sensors 16 are thus placed in or in connection to the rotor windings 12. Stator temperature sensors 30 may preferably also be placed in or in connection to the stator windings 26. The sensors are placed at positions, which based on analyses and/or experiments have been found to be critical for the winding. The sensors can be realised by placing e.g. resistive thermometers (Pt100 elements or similar thermoelements) in the stator winding 26 and/or rotor winding 12. For alternating current machines over 5 MVA it is a requirement in relation to IEC 34-1, section 7 to supply the stator winding 26 with ETD for thermal protection of the machine. To equip the stator winding 26 with a resistive thermometer is a preferred embodiment at use of the present invention. This gives therefore a very good control of the temperature and a safe and accurate material utilisation of the machine.

The signals from the rotor temperature sensors 16 are collected via a measurement unit/signal processor 18, which is connected to a transmitter

20 for wireless communication, arranged at the rotating shaft 10. A corresponding receiver 21 for wireless communication is arranged at the stationary parts of the machine. The communication is described more in detail below. The signals from the stator temperature sensors 30 and the measurement results transmitted to the receiver 21 are collected via a measurement unit/signal processor 32, which forwards the results to a processing unit 34. The processing unit is preferably a microprocessor. The processing unit 34 can then control the AC to DC converter 36 so that a suitable rotor current is obtained.

Fig. 11 shows a synchronous machine according to the present invention, where brushless magnetisation is used. Similar parts as in fig. 10 have been denoted by corresponding reference numerals and will not again be described. Only the, for the operation important, new parts are described below. Instead of providing the rotor windings 12 with a current via slip rings, a current is supplied by a magnetisation machine 58 arranged at the rotor shaft 10. The AC to DC converter 36 supplies a winding 50 on the stator 48 of the magnetisation machine with current. At rotation of the rotor shaft 10, a current is obtained in the windings 52 on the rotor 54 of the magnetisation machine. The current is converted from AC to DC by a converter 56 and is fed to the rotor windings 12. In a corresponding way as earlier are temperature sensors arranged at suitable places in or at the windings.

Fig. 12 shows a slip ring based asynchronous machine according to the present invention. Similar parts as in fig. 10 have again been denoted by corresponding reference numerals and will not again be described. Only the, for the operation important, new parts are described below. The power transformer 42 supplies here a frequency converter 60 with current. The frequency converter 60 transmits in turn alternating current via brushes 62 and slip rings 64 to the rotor 14. This machine is in a similar way as before provided with temperature sensors 16 and 30. The rotor temperature sensors 16 are, however, in this embodiment connected to an additional slip

ring 66 on the rotor shaft 10, and transfers the measurement information to a brush means 68 to the stationary part of the machine.

General methods used for monitoring the temperature of the rotor or its insulation are available also by indirect measurement. Rotor current may then be used for indirect temperature measurement. However, even if heat tests are performed when the machine is in operation, indirect measurement generally gives a worse accuracy. Furthermore, indirect measurements often give only averaged temperature indications and the temperatures in critical points may be considerably higher, which calls for use of temperature margins anyway.

According to the present invention, the rotor winding temperature and/or the temperature of its insulation is measured by direct measurements, preferably at critical points. To equip the rotor winding with resistive temperature sensors is a preferred embodiment at use of the present invention for both synchronous and asynchronous machines.

For alternating current machines with winded rotor, the control unit that controls the rotor current is traditionally placed stationary on the outside of the machine. With brushless magnetisation of a synchronous machine, the rotor current is in general regulated by controlling the magnetisation to the magnetisation machine, as it is shown in fig. 11. With static magnetisation of a synchronous machine, the AC to DC converter is normally placed outside the machine and the current is transferred via slip rings to the rotor winding, as shown in fig. 10. An asynchronous machine with winded rotor is normally designed with slip rings so that the rotor winding can be fed by an alternating voltage or current from a frequency converter which is placed outside the machine. A common feature for these alternatives is that when the control unit for the rotor current is placed outside the machine (and not on the shaft), a communication line is needed between rotor and stator. This may be realised in several ways depending on demands on the number of measurement points and accuracy and what should be measured.

For measuring of rotor temperature, it is a preferred embodiment to mount 2 - 10 temperature sensors (e.g. Pt-100 elements) at selected places in the rotor winding and to transfer the measurement signals to the stationary control unit via a digital radio connection between stator and rotor, as shown in fig. 10 and 11. Energy to the communication line and measurement system is fetched from a stabilised current supply, which is placed at the shaft of the machine and which collects its energy from the rotor winding.

Alternatively, analogue communication may be used. The communication may then be made wireless or, as shown in fig. 12, via slip rings.

In the embodiment described above, measurement data concerning winding temperature is sent to a processing unit. This processing unit is used in one embodiment of the present invention for control of the rotor current. This may simply be made by, as suggested in the figures 10-12, connecting the processing unit to a converter or current generator. The temperature information may also be used for controlling stator currents. In a simple implementation of this control method, the control of the current is based only on the measured temperatures and outer provided data about desired operation. Other information may, however, also be usable at the control of the currents. Such information may e.g. be constituted by calibration measurement.

It has during the later decades existed a distinct trend to miniaturise electronics for signal processing. Telecommunication may be considered to be almost totally digital today in its essential parts. Signal processing in control and regulating circuits has also been miniaturised and it is easy to implement internal digital signal processing into e.g. current converters, both AC to DC converters and DC to AC (direct to alternating current) converters. To design such circuits with analogue technique does not involve any additional value, since the digital resolution both concerning amplitude

and time is large enough. Digital communication is also to prefer because of other aspects such as the possibilities to set and trim the parameters of the regulation circuits at a distance. An original parameter setting may thus be changed during operation to a modified parameter setting based on earlier operational data.

A preferred embodiment of the control system is schematically shown in fig. 13. A processing unit 100 is arranged to receive measurement results from temperature measurements from rotor temperature sensors 104. Preferably, also stator temperature measurements are provided by stator temperature sensors 102. The processing unit 100 is furthermore connected to a control means 108, which is concerned with control of stator and/or rotor current. The processing unit 100 is in this preferred embodiment also connected to a storage unit 106 for temperature data. This temperature data may also comprise simple limit information that may be provided by manual input, such as information about nominal and maximum stator and rotor temperature. The data may also comprise measured and/or estimated relations between rotor and stator current, and rotor and stator temperature at stationary states. Such data may e.g. be provided at calibration runs. Furthermore, the measured temperatures may during operation be stored and as time goes processed, to update and correct such relations. Also data that describes the temperature history of the rotor and stator may be stored, in order to be used at decisions about how hard the machine can be run.

A processing unit 100 with access to a well-supplied database of temperature information may be programmed in a suitable manner to provide a very intelligent control of the material margins of a machine. The content of the database may be used in order to, at every occasion, calculate the gathered temperature margin that is available in an alternating current machine. In an emergency situation, e.g. if a voltage collapse of the electric power network is dangerously close, such temperature margins may then easily be used to temporarily rescue the situation. A deliberate operation of the machine over its rated values may according to the present invention be

performed due to the reliable supervision of the temperature development in the machine.

The processing unit 100 may also be used to implement a flexible and intelligent protection or limitation device for the machine. If something exceptional occurs, such as a faulty net voltage, the operational state of the machine is normally changed. By being able to detect e.g. the time derivative of temperatures in the windings, a fault may rapidly be detected. This may also be used as a pure indication of certain electric power network faults, such as being described in "Rotor heating as an indicator of system voltage instability", IEEE Trans. on Power Systems, Vol. 10, No. 1, Feb. 1995, pp. 175-81. To avoid that a machine is totally turned off, and thereby aggravate the condition for an already unstable electric power network, the machine may in such situations be turned over to run in some other operational state, that doesn't risk to heat up the stator or rotor to forbidden temperatures. Furthermore, one could in such situations on purpose let the machine be warmer than the nominal temperature, while taking care of the fault that causes the heating. However, one has always to make sure that the temperatures always are kept below a maximum level, where risk for damages on the machine is present also for a shorter operational period.

A control of the machine in order to avoid turn-off may normally be driven to a certain limit, when e.g. the relation between active and reactive power becomes so exceptional that the machine is risking to become unstable. A soft and well-regulated turning-off may then be performed.

The concept with information about thermal material margins may also be brought out on an electric power plant level or electric power network level. Electric power plant is in this application referring to a construction comprising a group of alternating current machines, which are situated within a limited area and are operated in a co-ordinated manner and which preferably belong to the same operator. An electric power plant according to the above definition may typically consist of a number of alternating current

machines, transformers, lines, cables, bus bars, disconnecting switches and circuit breakers and accompanying measuring and setting devices. An electric power network is in this application referring to a network of connected electric power plants, which typically are spread over a wider geographical area.

Fig. 14a and 14b show schematically an electric power plant, in which a number of alternating current machines 202 are comprised. Together with control equipment for the machine, the alternating current machine 202 constitutes a machine unit 211. Each machine unit 211 constitutes a part of an electric power plant (according to earlier definition), which via power lines or cables 201 is connected to a electric power network 200. The machines are equipped with temperature sensors 203 according the present invention, and temperature data is collected by a control unit 204 at each machine. The control unit 204 comprises logically the processing unit in the earlier description. A group of machine units 211 are generally controlled by a plant management unit 206. According to the present invention, a number of communication devices 205 are established between the control units 204 for the machines and the plant management unit 206. If a fault occurs in the network, the plant management unit 206 may transfer information about this to the different control units, perhaps connected to a request about to temporary being able to drive the machines in a particular way. The respective control units 204 may at their side inform the plant management unit 206 about its present operational state and if any tendencies of network instabilities have been detected.

Such a configuration becomes particularly powerful if the plant management unit 206 has access to the current temperature condition for the different machines, i.e. to the temperature measurement values or associated quantities calculated therefrom. In the same way as for the control of each separate machine, additional temperature data is also of interest. If the plant management unit 206 has access to both the present temperature for the different machines and stored information about how large temperature

margins that is present in each of the machines, this may be utilised to continuously update the operational plans for how to be able to handle different faults or operational situations. If the plant management unit 206 knows that a certain machine has a large margin to utilise, this may be requested at a fault situation, in order to maybe save other machines with smaller margin still in the network.

A database with temperature data for the different machines is thus to prefer. This may be arranged in connection to each control unit, such as described above. The temperature database or a copy of it may also be available in the plant management unit 206, so that no temporarily disconnected information connections may jeopardise the possibilities for control. The plant management unit 206 therefore preferably comprises a memory means for storing of the database. The information in the database may at a later occasion be used for analysis in order to increase the knowledge about the behaviour of the plant at normal operation as well as at disturbances. The information may also be used to analyse the efficiency of the plant and to be able to plan future operation modes. The database thus comprises both historic information, concerning the earlier operation of the machines, but also information that is needed for accomplishing a suitable control of the machines. The database may e.g. comprise the response of the machine at earlier occurring disturbances.

The network communication devices 205 may operate according to different communication methods according to prior art. Such methods may be based on stationary connections in the form of e.g. metallic wires or fibre optics, or on wireless transmission, such as radio or radio relay link. At connection of several production management units, a network of communication devices may be built. Such a network contributes to alternative communication paths, which may be utilised in case any or some communication devices by some reason are not available. By suitable combinations of redundant communication paths and storage of information in databases, the production management unit 206 may perform calculations and updates of

operation plans, for instance by extrapolating the sate in machines and using the results from eigenvalue calculations, even if any or some communication devices and/or sensors at the present do not operate. The possibility to build up a reliable network is of particular importance for instance at strained operational situations or during the rebuilding of the operation after a larger operation disturbance.

The concept with utilisation of construction margins may, as was earlier indicated, also be brought out on electric power network level. Means for control and supervision of the electric power network, a network supervision unit 212, is responsible for the operation of the electric power network in large, and may in a corresponding way as described above communicate with the plant management units 206 of the electric power plants or separate electric machines 202, in order to get information about possible margins. These margins may then be used for an optimisation of larger areas or the total operation of the electric power network.

The information that is transferred from an electric power plant or separate electric machine to a network supervision unit 212 on electric power network level, would probably preferably be of a more summarised type than lower down in the hierarchy. An electric power network operator has mainly interest of to known available power resources on different places in the network and the possible costs that are connected with the use of them. The detailed conditions regarding the individual temperature margins of the machines are of less interest, especially for an hierachially superior electric power network operator. It is also of interest for an operator on an electric power plant to be able to limit the information exchange, since a part of the available information may be used as competitive means to competing operators. The tasks of the network supervision unit 212 are to secure the possibilities for a safe and economically optimum operation of the electric power network. This may comprise communication of information exchange and target values as well as control signals to both production management units 206 and electric power networks 200. During normal operation

conditions, the control of production management units 206 may be based on economical control signals, while it might be necessary to send direct control commands at serious operation disturbances, with the aim to save the integrity and continuous operation of the electric power network. The information exchange between the network supervision unit 212 and the rest of the units should be performed in the form of messages, which can besides address and message can contain security keys (coding) to limit the ones that have the right to take part of the information. By utilising different authorization criteria for different units (utilisers) in the communication system, an adequate secrecy against unauthorised distribution of information be obtained. The possibility to determine which information each utiliser has access to reduces the risk for distribution of sensitive information and enables for instance for cooperation partners to get access to more information than other totally external parties.

A preferred embodiment of a plant management unit 206 in an electric power plant thus comprises a means for external communication. This means is arranged partly to receive and interpret messages from external units, such as e.g. an operator of an electric power network and partly to send out selected information to the external units.

The present invention may of course be utilised at installation of new equipment in an electric power network. The methods and the devices are, however, of such a kind that they advantageously also may be used at restoration of existent equipment. In many cases, restoration of old equipment leads to large thermal material margins, if turbines or other mechanical arrangements can't be upgraded in the same extent, whereby these machines advantageously may be utilised for control purposes.

Fig. 15 schematically shows the control method for a rotating electric alternating current machine according to the present invention. The process starts in step 300. In step 302, the temperature of the rotor winding and/or its insulation is measured continuously or intermittent. In step 304, these

measurement data are used to control the continuous operation of the alternating current machine, so that a thermally controlled optimisation of the power conversion is obtained. The process is ended in step 310.

Fig. 16 schematically shows the protection method for a rotating electric alternating current machine according to the present invention. The process starts in step 300. In step 302, the temperature of the rotor winding and/or its insulation is measured continuously or intermittent. In step 306, these measurement data are used to control the winding currents so that the temperature of the windings is regulated within permitted values. The process is ended in step 310.

Fig. 17 schematically shows the control method of an electric power plant according to the present invention. The process starts in step 300. In step 302, the temperature of the rotor winding and/or its insulation of alternating current machines in the electric power plant is measured continuously or intermittent. In step 308, these measurement data are used to control the power conversion of the electric power plant in a controlled and optimum manner. The process is ended in step 310.

Anyone skilled in the art realises that different modifications and alterations can be done of the present invention without deviation from the scope of the invention, defined by the enclosed patent claims.

CLAIMS

1. Method for control of the power conversion for rotating electric alternating current machine, having a stator (28) and rotor (14) with windings (26, 12) having solid insulation, **characterised by** the steps of:

direct measuring, continuously or intermittently, of the temperature of critical points of the rotor winding (12) and/or its insulation; and

optimising of the power conversion of the alternating current machine in a thermally controlled manner by controlling of the continuous operation of the alternating current machine using measured temperature as control parameter for rotor current.

2. The method according to claim 1, **characterised by** the further step of:

direct measuring, continuously or intermittently, of the temperature of critical points of the stator winding (26) and/or its insulation, whereby the step of optimising is performed using also the measured stator winding temperature.

3. The method according to claim 1 or 2, **characterised in that** the step of optimising in turn comprises the step of controlling, during a limited period of time, the rotor current to a value, which exceeds respective rated values.

4. The method according to claim 3, **characterised in that** the step of optimising further comprises the step of controlling, during a limited period of time, the stator current to a value, which exceeds respective rated values.

5. The method according to any of the claims 1 to 4, **characterised in that** the step of optimising, at generator operation, changes the relation between extracted active power and extracted/supplied reactive power.

6. The method according to any of the claims 1 to 5, **characterised in that** the step of optimising, at generator operation, changes the amount of extracted/supplied reactive power.

7. The method according to any of the claims 1 to 4, **characterised in that** the step of optimising, at motor operation, changes the relation between supplied active power and extracted/supplied reactive power.

8. The method according to any of the claims 1 to 4 and 7, **characterised in that** the step of optimising, at motor operation, changes the amount of extracted/supplied reactive power.

9. The method according to any of the claims 1 to 8, **characterised in that** the optimisation is performed such that a predetermined maximum value of the temperature of the rotor winding (12) and/or its insulation never is exceeded.

10. The method according to claim 9, **characterised in that** the optimisation is performed such that a predetermined maximum value of the temperature of the stator winding (26) and/or its insulation never is exceeded.

11. The method according to any of the claims 1 to 10, **characterised in that** the optimisation is performed such that the nominal value of the temperature of the rotor winding (12) and/or its insulation only is exceeded during a limited period of time.

12. The method according to claim 11, **characterised in that** the optimisation is performed such that the nominal value of the temperature of the stator winding (26) and/or its insulation only is exceeded during a limited period of time.

13. The method according to any of the claims 1 to 12, **characterised in that** the controlling of the continuous operation of the alternating current machine uses parameters possible to calibrate, whereby the method further comprises the step of:

modifying of the parameters possible to calibrate, based on earlier operational data.

14. Method for control of the power conversion in an electric power plant, comprising at least one rotating electric alternating current machine (202), having a stator and rotor with windings having solid insulation, **characterised by** the steps of:

direct measuring, continuously or intermittently, of the temperature of critical points of the rotor winding and/or its insulation; and

when the electric power plant has an undesired distribution of conversion of active and reactive power, optimising of the power conversion of the alternating current machine (202) in a thermally controlled manner by controlling of the continuous operation of the alternating current machine using measured temperature as control parameter for rotor current.

15. The method according to claim 14, **characterised in that** the optimising of the power conversion is performed, based on pre-stored information about the temperature margins of the alternating current machine (202).

16. The method according to claim 14 or 15, **characterised by** the further step of:

communicating of data concerning the operation of the alternating current machine (202) from the control unit (34; 204) to a plant management unit (206) belonging to the electric power plant.

17. The method according to claim 14, 15 or 16, **characterised by** the further step of:

communicating of instructions and/or inquires concerning the operation of the alternating current machine (202) from the plant management unit (206) to the control unit (34; 204).

18. The method according to claim 16 or 17, **characterised in that** the communication between the plant management unit (206) and the control unit (34; 204) is performed via metallic wires or optical fibres.

19. The method according to claim 16 or 17, **characterised in that** the communication between the plant management unit (206) and the control unit (34; 204) is performed via radio or radio relay links.

20. The method according to any of the claims 14 to 19, **characterised by** the step of:
transmission of messages between the plant management unit (206) and external units.

21. Rotating electric alternating current machine comprising:
a stator (28) with windings (26) having solid insulation,
a rotor (14) with windings (12) having solid insulation, and
a control unit (34; 204) for control of rotor current , and
characterised by
at the rotor windings (12) and/or its insulation arranged, rotor temperature sensor (16; 203), which communicates with the control unit (34; 204),
whereby signals from the rotor temperature sensor (16; 203) is the basis of the control of the rotor current.

22. The rotating electric alternating current machine according to claim 21, **characterised in that**
the control unit (34; 204) is arranged for control of stator current; and
by at the stator windings arranged stator temperature sensor (30; 203), which communicates with the control unit (34; 204);
whereby signals from the stator temperature sensor (30; 203) is the basis for the control of the stator current.

23. The rotating electric alternating current machine according to claim 21 or 22, **characterised in that** the control unit (34; 204) is arranged at a stationary part of the alternating current machine and that the alternating current machine further comprises communication means (20, 21; 66, 68) for transferring of information from the rotor temperature sensor (16, 203) to the control unit (34; 204).

24. The rotating electric alternating current machine according to claim 21, 22 or 23, **characterised in that** the communication means is a wireless communication means (20, 21).

25. The rotating electric alternating current machine according to any of the claims 21 to 24, **characterised by** a storage unit (106) for storage of temperature data for the alternating current machine.

26. The rotating electric alternating current machine according to claim 25, **characterised in that** the temperature data comprises at least one of the following types of data:

nominal stator temperature,

nominal rotor temperature,

maximum stator temperature,

maximum rotor temperature,

relation between rotor current and rotor temperature at stationary condition,

relation between stator current and stator temperature at stationary condition,

the temperature history of the rotor, and

the temperature history of the stator.

27. Electric power plant comprising:

a number of rotating electric alternating current machines (202), having a stator (28) and a rotor (14) with windings (26; 12) having solid insulation,

a plant management unit (206); and

characterised in that

at least one of the rotating electric alternating current machines (202) comprises a control unit (34; 204) for control of rotor current, and at the rotor winding (26; 12) and/or its insulation arranged temperature sensor (16, 30; 203), which communicates with the control unit (34; 204),

whereby signals from the temperature sensor (16, 30; 203) is the basis for the control of rotor current.

28. The electric power plant according to claim 27, **characterised by** communication devices (205) between the control unit (34, 204) and the plant management unit (206) for transferring of information associated with the signals from the temperature sensors.

29. The electric power plant according to claim 28, **characterised in that** the communication devices (205) comprise physical lines in the form of metal wires or optical fibres.

30. The electric power plant according to claim 28, **characterised in that** the communication devices (205) comprise means for transmission via radio or radio links.

31. The electric power plant according to any of the claims 27 to 30, **characterised by** a storage unit (106) for temperature data for the alternating current machine.

32. The electric power plant according to claim 31, **characterised in that** the storage unit (106) for temperature data is comprised in the control unit (34; 204).

33. The electric power plant according to claim 31, **characterised in that** the storage unit (106) for temperature data is comprised in the plant management unit (206).

34. The electric power plant according to claim 31, 32 or 33, **characterised in that** the temperature data for the alternating current machine comprises at least one of the following types of data:

nominal stator temperature,

nominal rotor temperature,

maximum stator temperature,

maximum rotor temperature,

relation between rotor current and rotor temperature at stationary condition,

relation between stator current and stator temperature at stationary condition,

the temperature history of the rotor, and

the temperature history of the stator.

35. The electric power plant according to any of the claims 27 to 34, **characterised in that** the plant management unit (206) comprises means for transferring of messages to and from external units.

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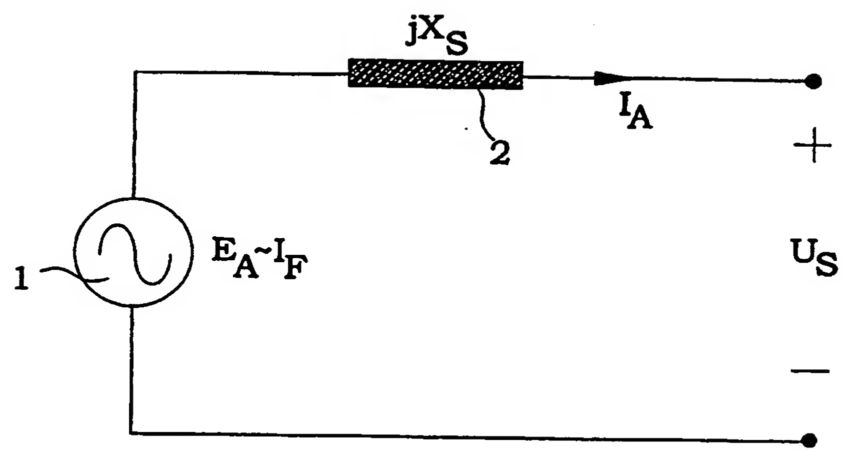


Fig. 1a

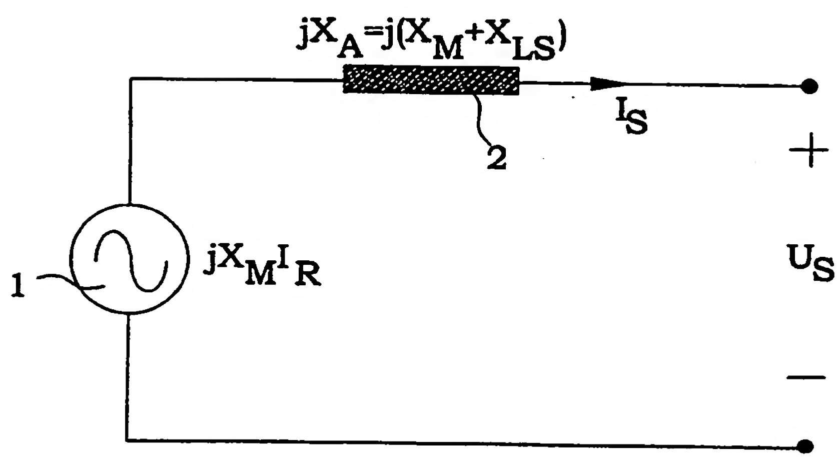


Fig. 6a

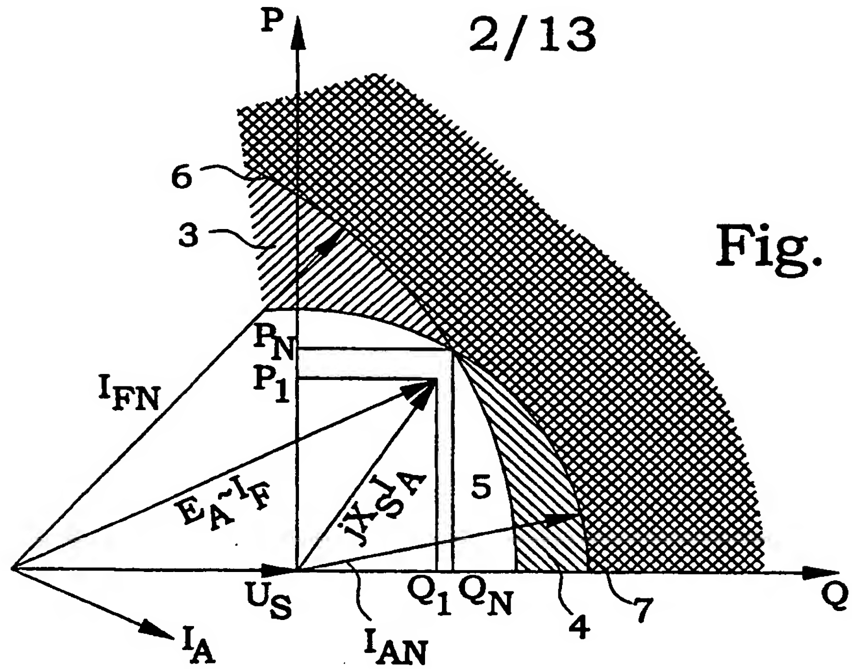
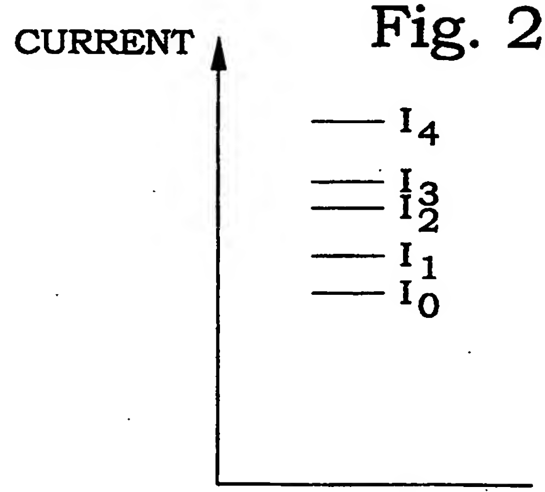


Fig. 1b

Fig. 2a



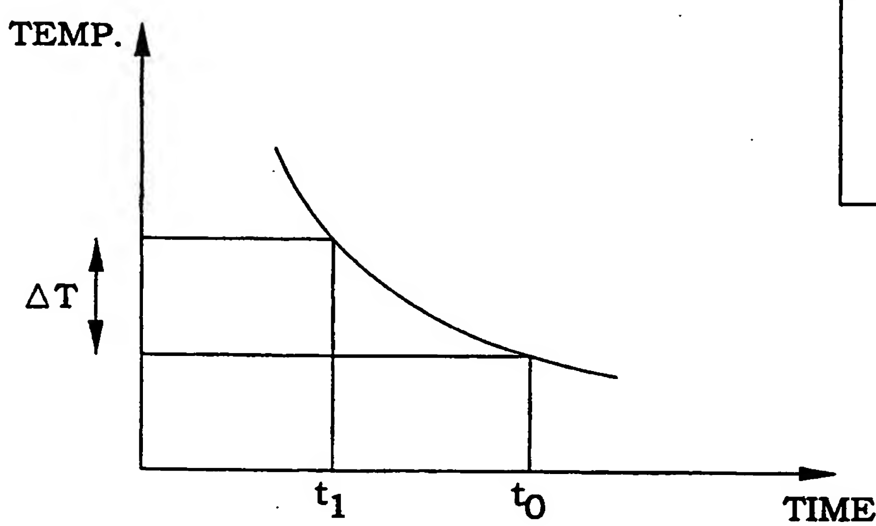


Fig. 2b

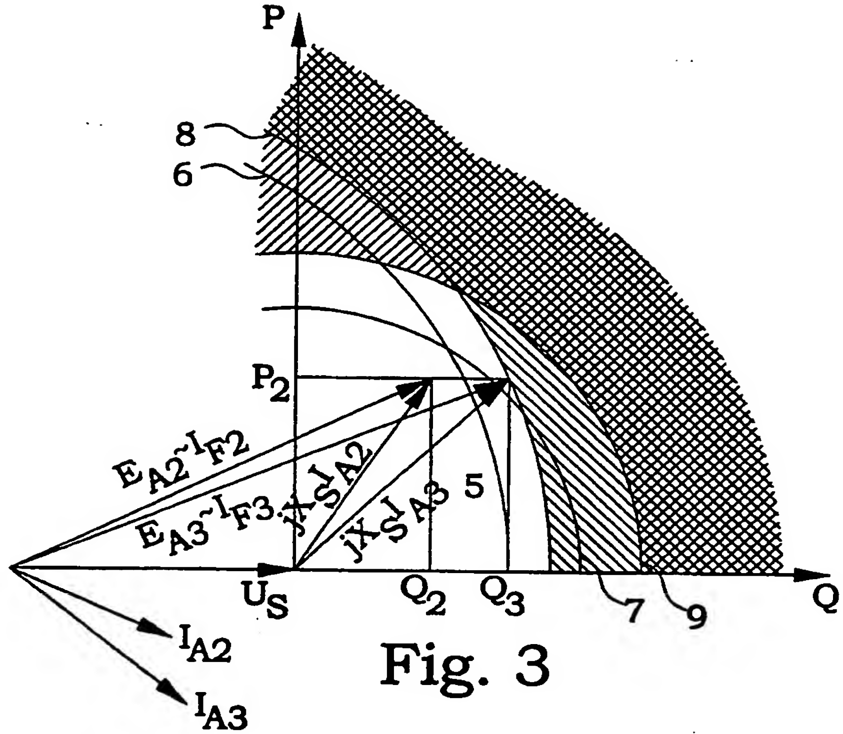
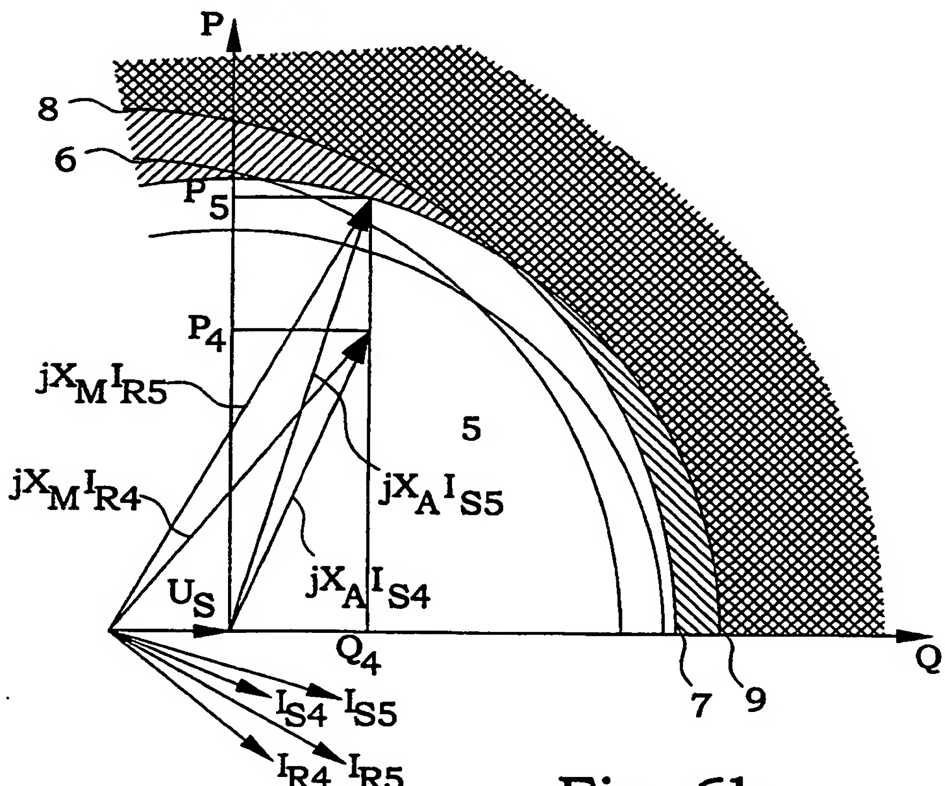

P
8
6
P2
EA2~IF2
EA3~IF3
jXSIA2
jXSIA3
5
US
Q2
Q3
7
9
Q
IA2
IA3

Fig. 3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P5
P4
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jXMIR4
jXAIS5
jXAIS4
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US
Q4
7
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IS4
IS5
IR4
IR5

Fig. 6b

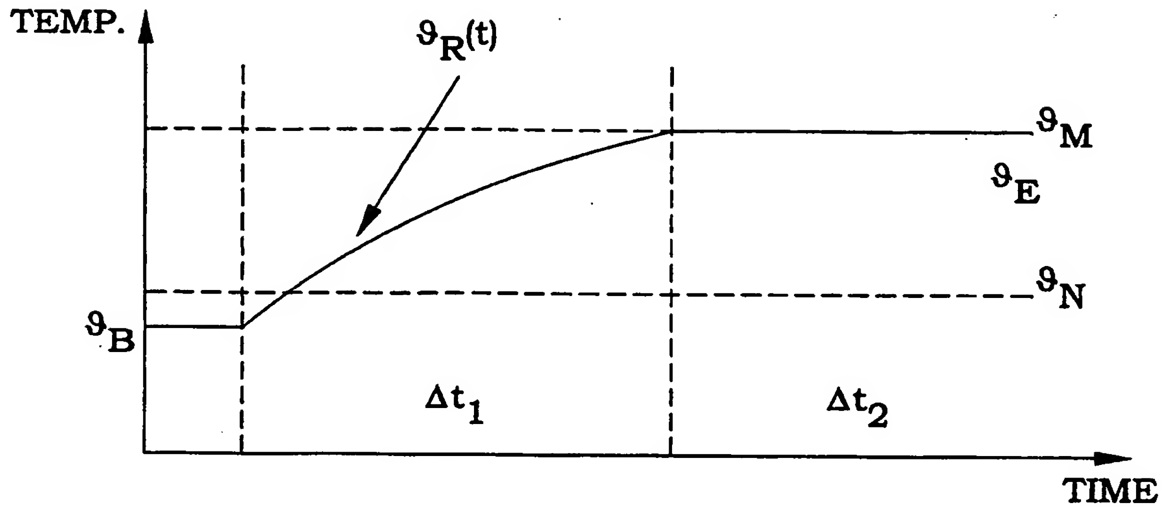

TEMP.
$\vartheta_R(t)$
ϑ_M
ϑ_E
ϑ_N
ϑ_B
Δt_1
Δt_2
TIME

Fig. 4a

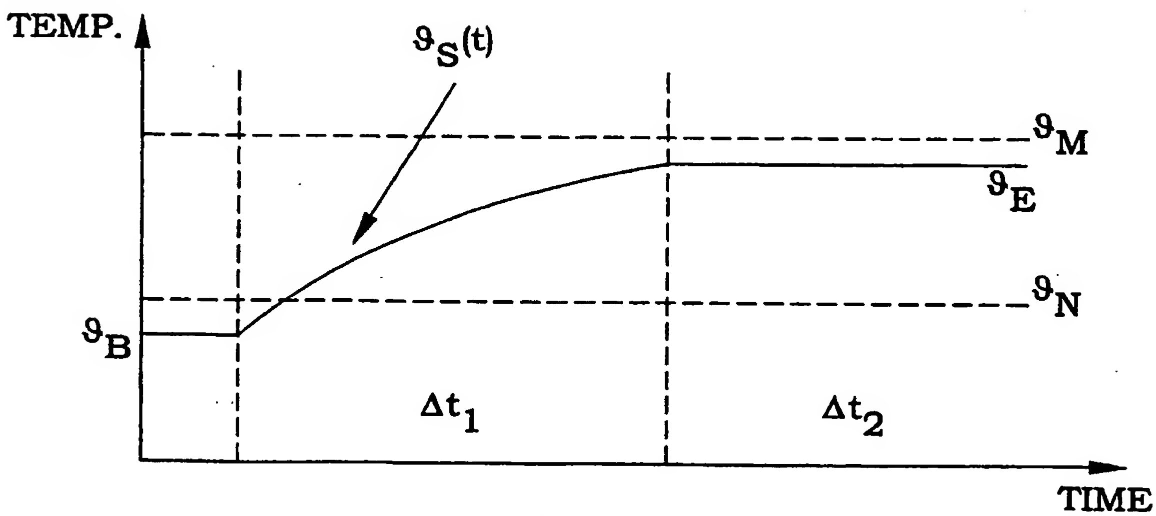

TEMP.
$\vartheta_S(t)$
ϑ_M
ϑ_E
ϑ_N
ϑ_B
Δt_1
Δt_2
TIME

Fig. 4b

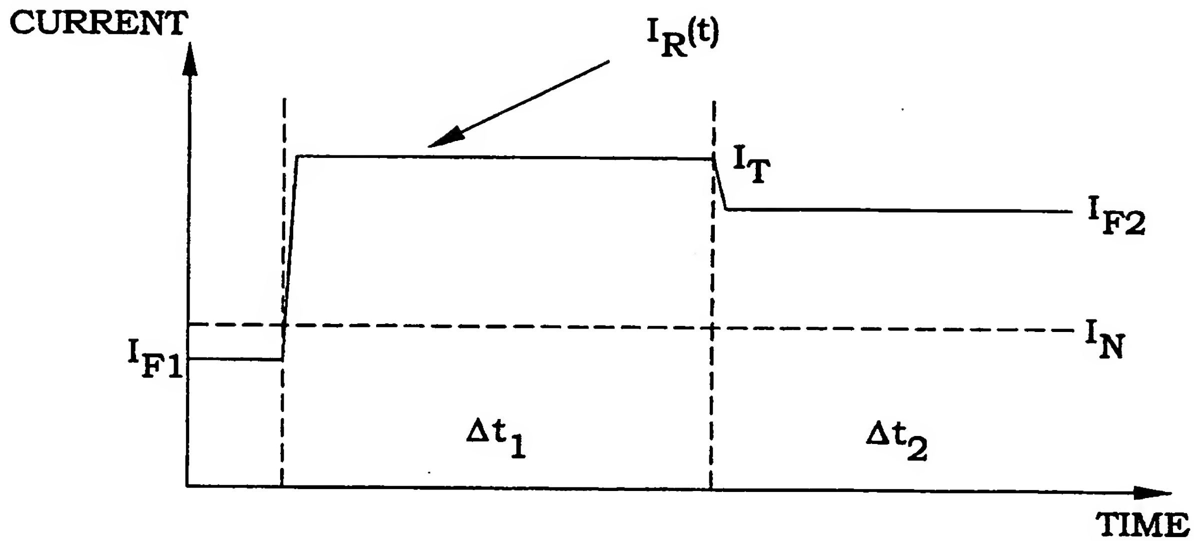

CURRENT
$I_R(t)$
I_T
I_{F2}
I_N
I_{F1}
Δt_1
Δt_2
TIME

Fig. 5a

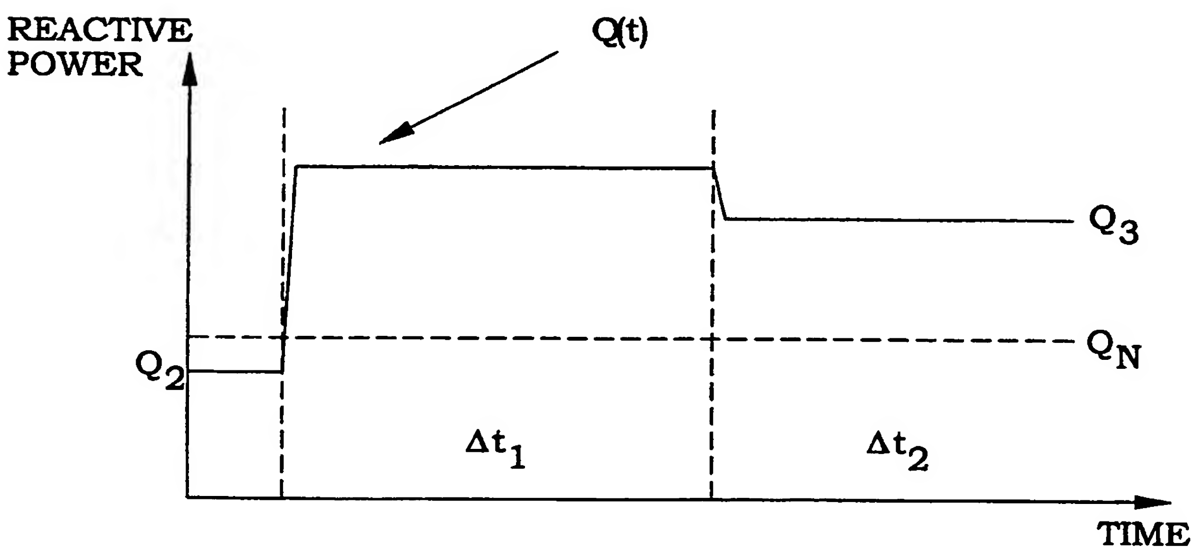

REACTIVE POWER
Q(t)
Q_3
Q_N
Q_2
Δt_1
Δt_2
TIME

Fig. 5b

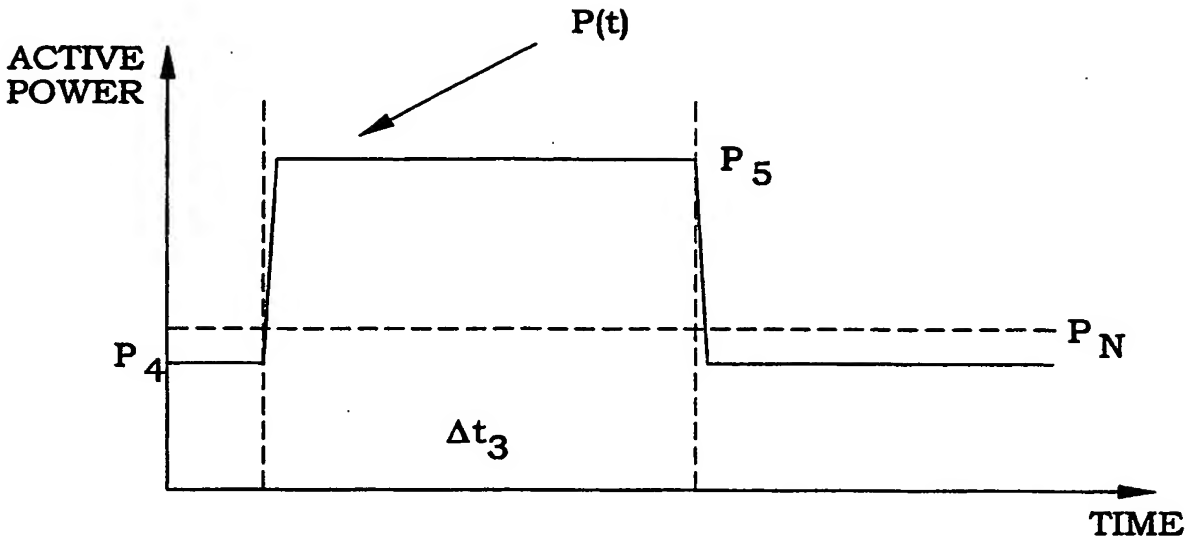

P(t)
ACTIVE POWER
P_5
P_N
P_4
Δt_3
TIME

Fig. 7a

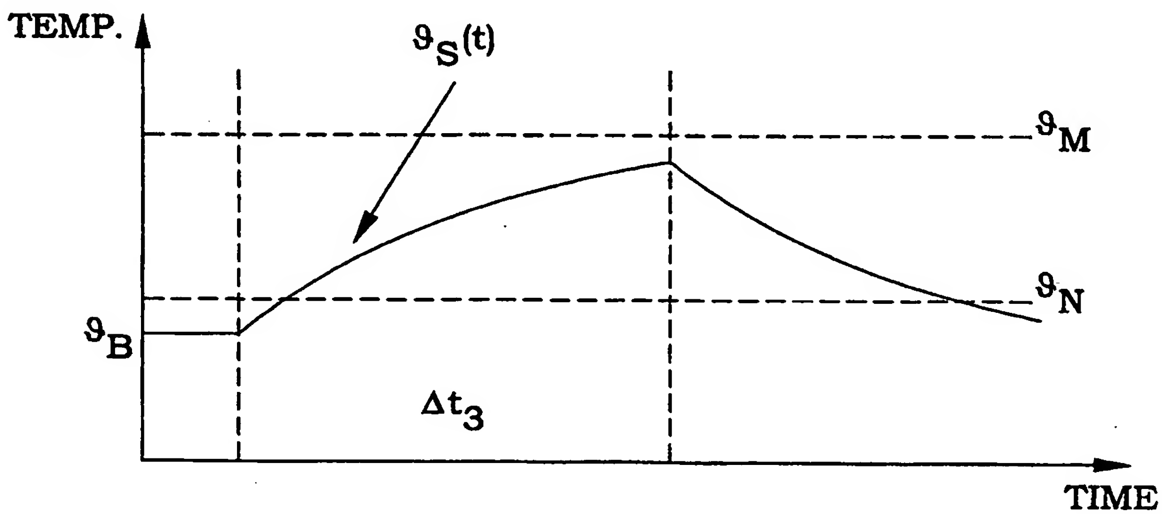
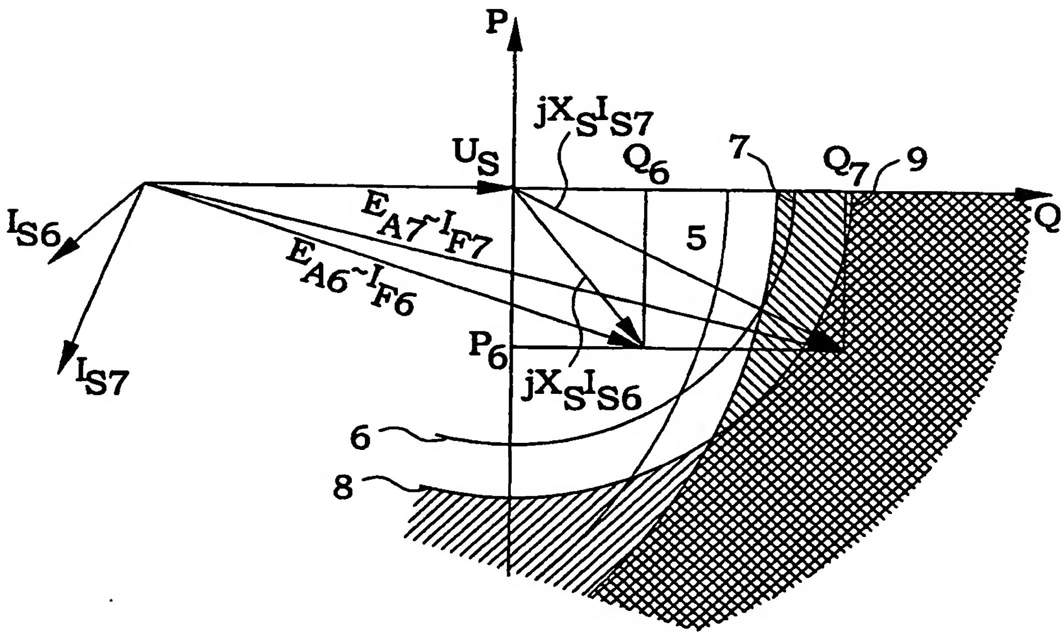

TEMP.
$\vartheta_S(t)$
ϑ_M
ϑ_N
ϑ_B
Δt_3
TIME

Fig. 7b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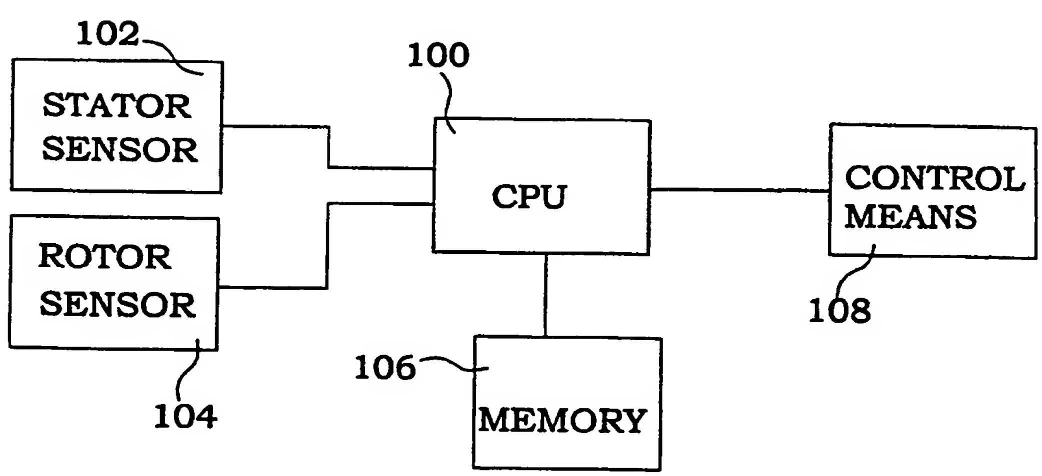
US
Q6
7
Q7
9
Q
IS6
EA7~IF7
5
EA6~IF6
P6
IS7
jXSIS6
6
8

Fig. 8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STATOR SENSOR
100
CPU
CONTROL MEANS
ROTOR SENSOR
108
106
MEMORY
104

Fig. 13

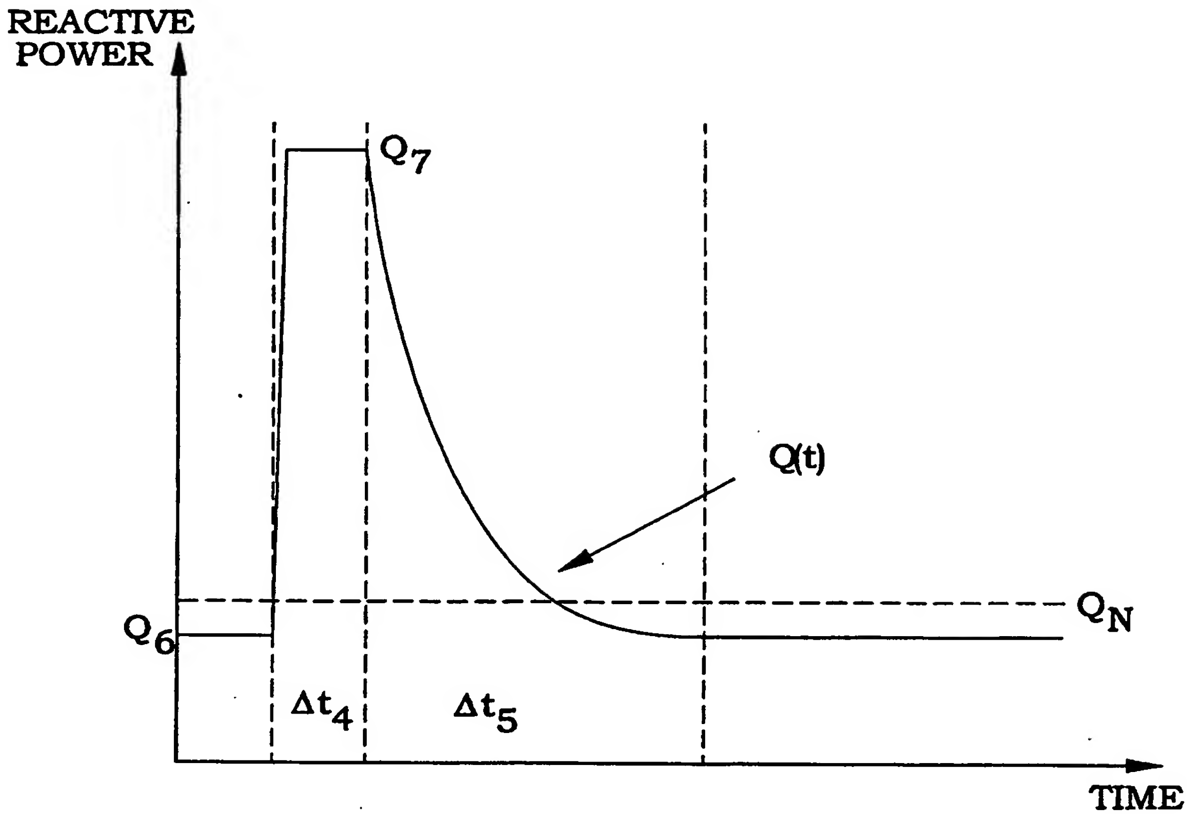
REACTIVE POWER
Q7
Q(t)
QN
Q6
Δt4
Δt5
TIME

Fig. 9a

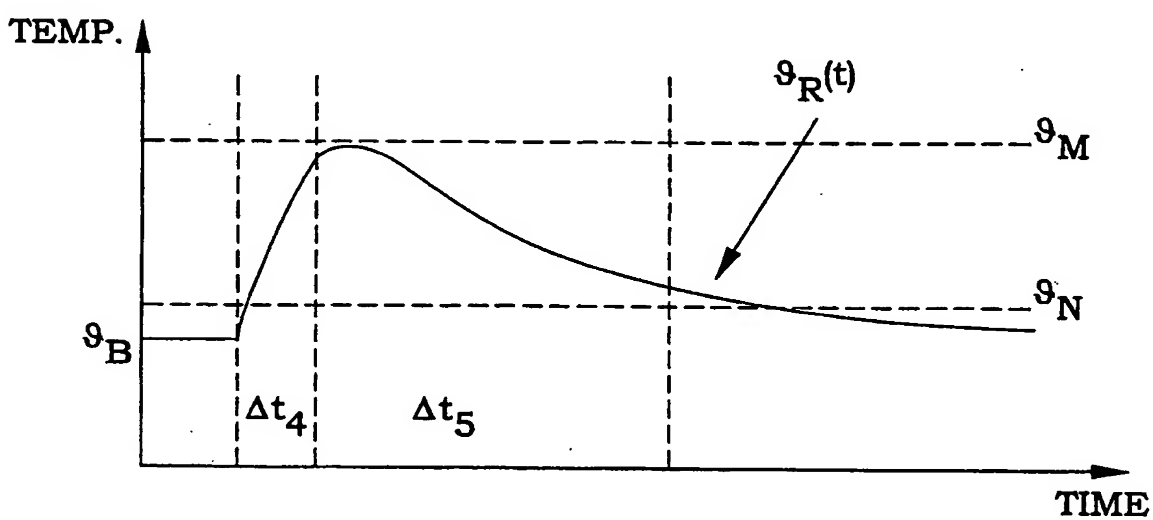
TEMP.
ϑR(t)
ϑM
ϑN
ϑB
Δt4
Δt5
TIME

Fig. 9b

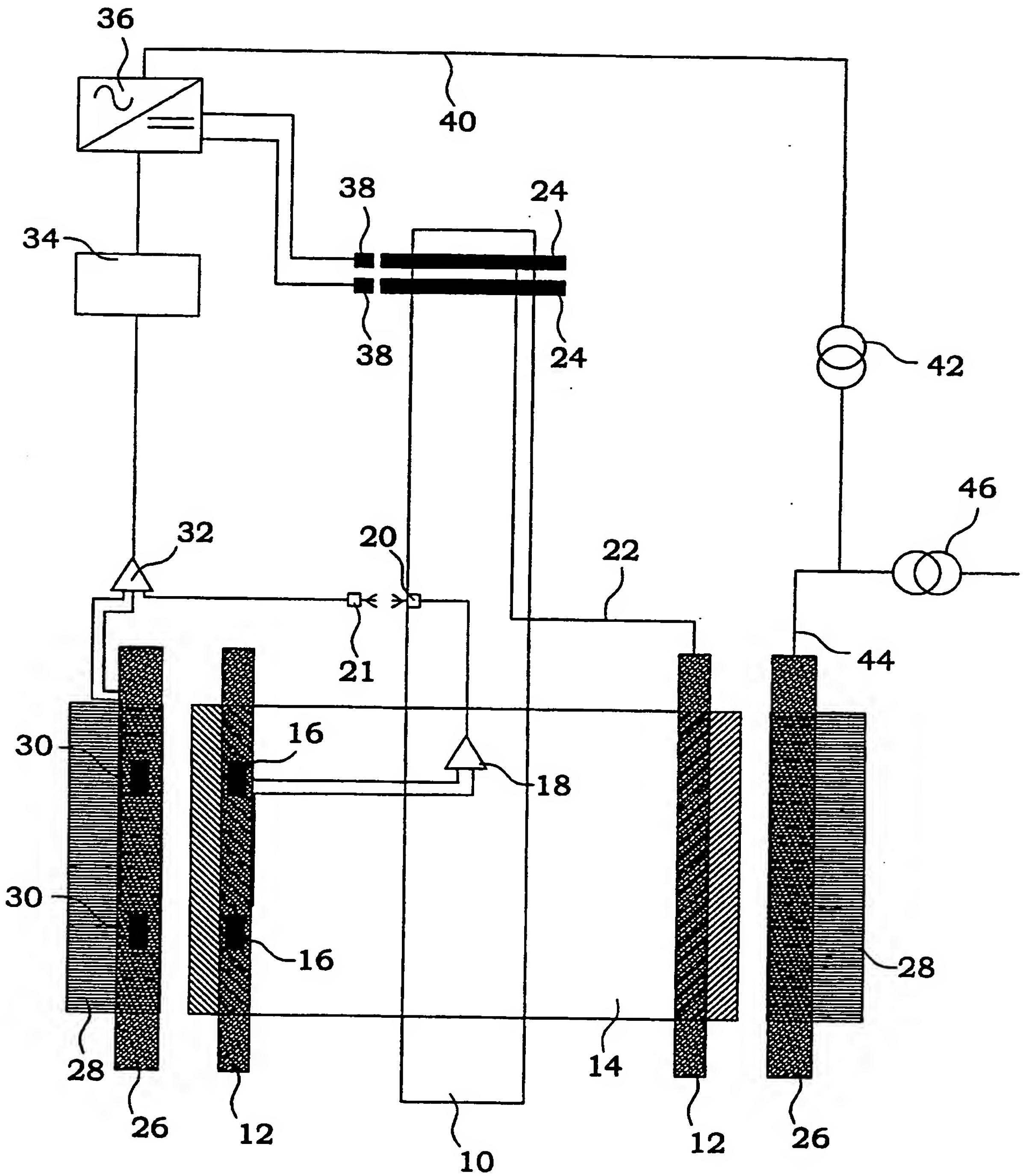
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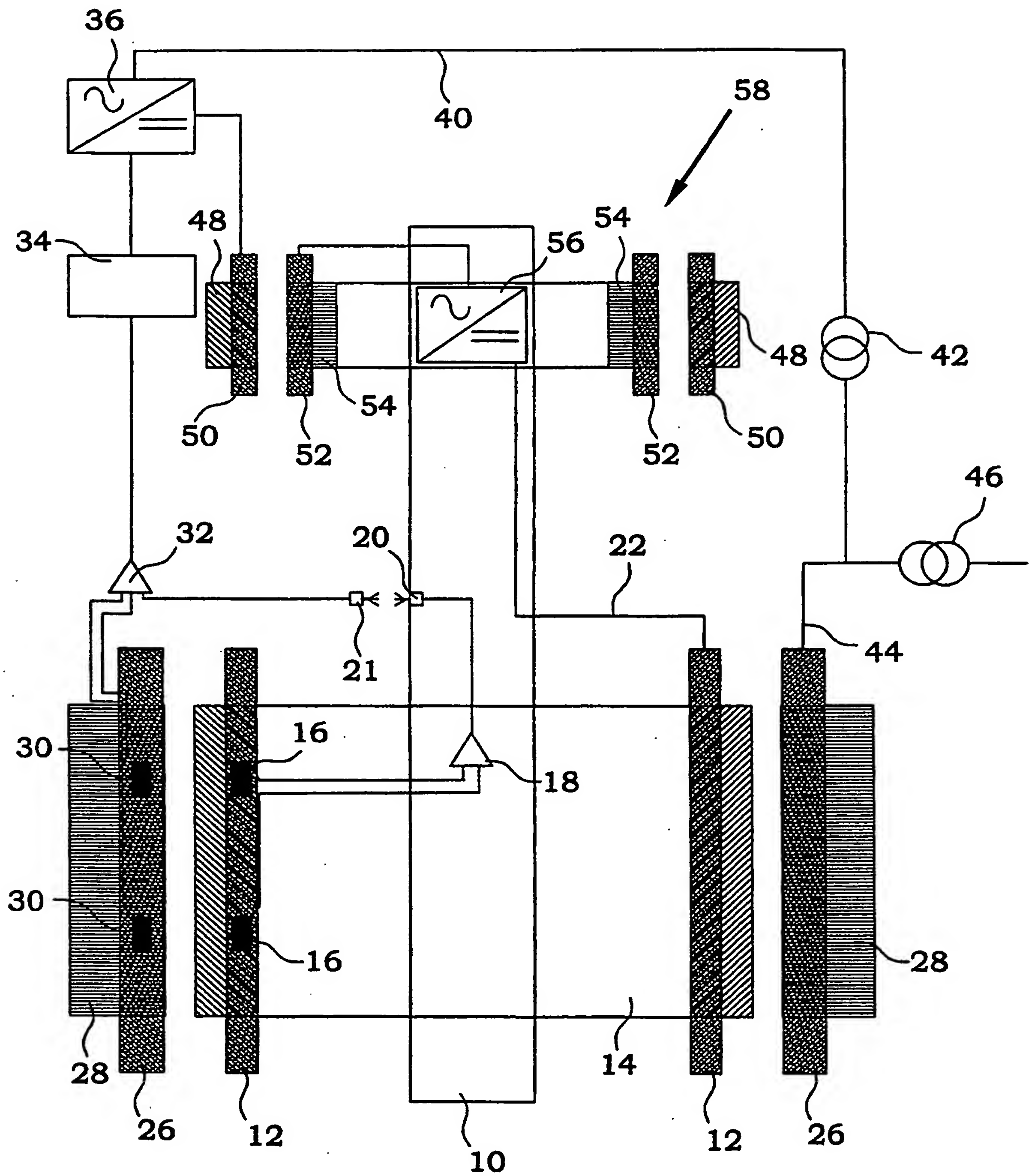
Fig. 10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12
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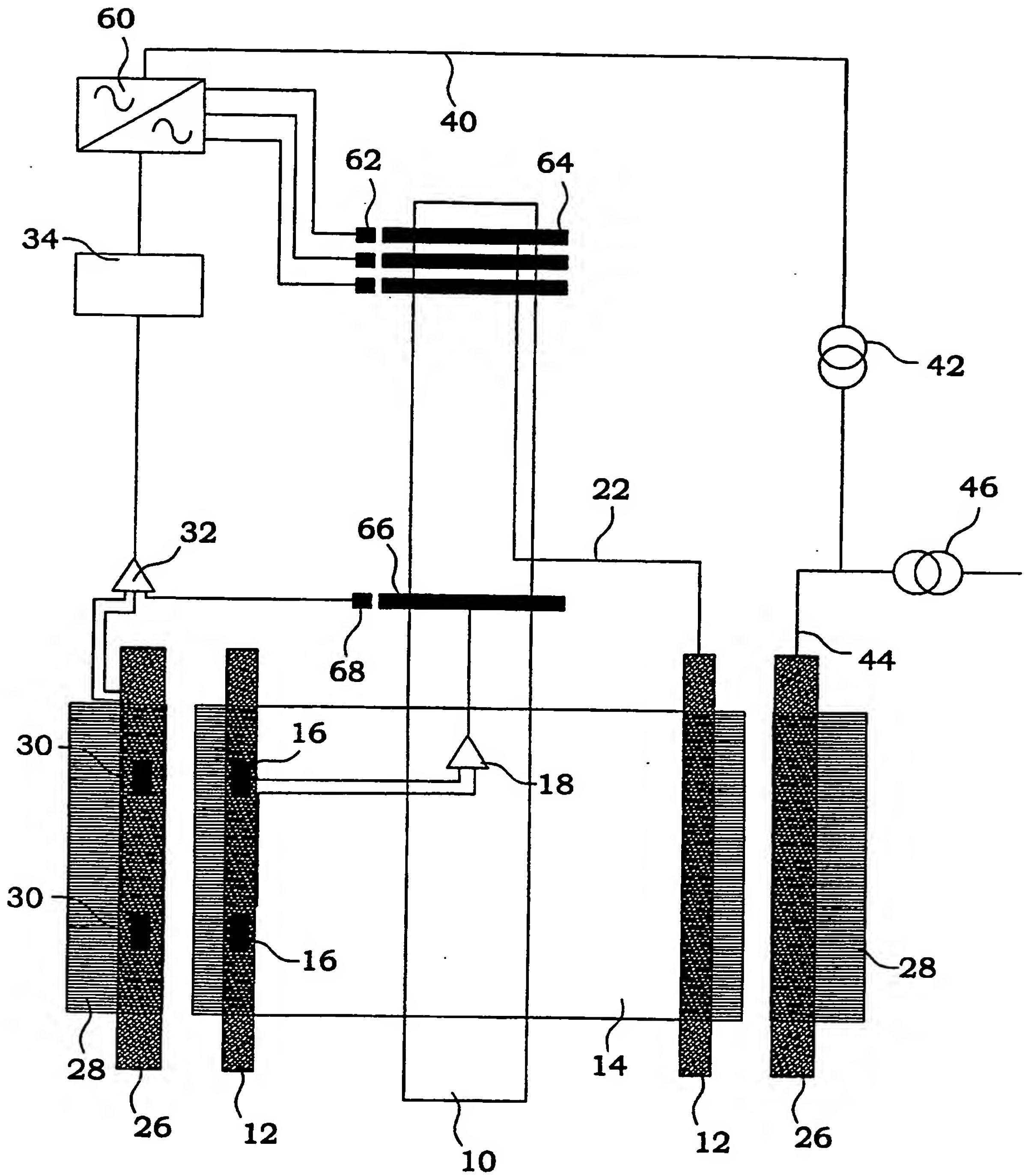
Fig. 11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12
26

Fig. 12

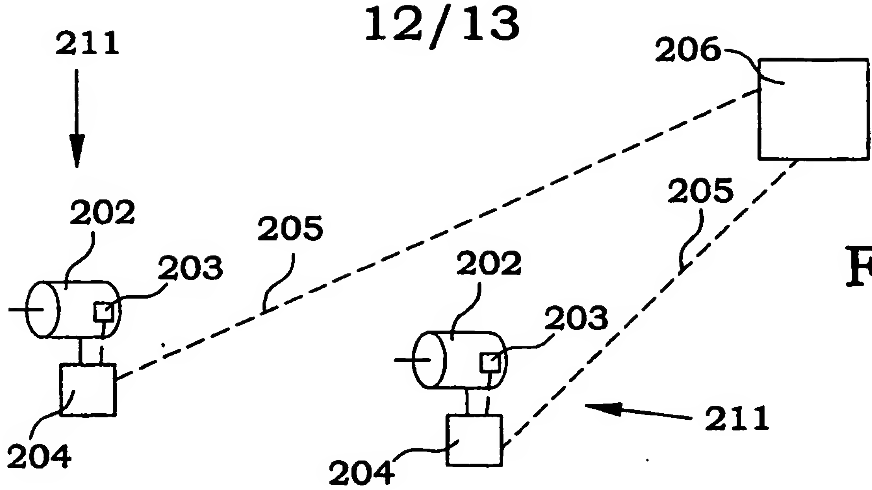

Fig. 14a

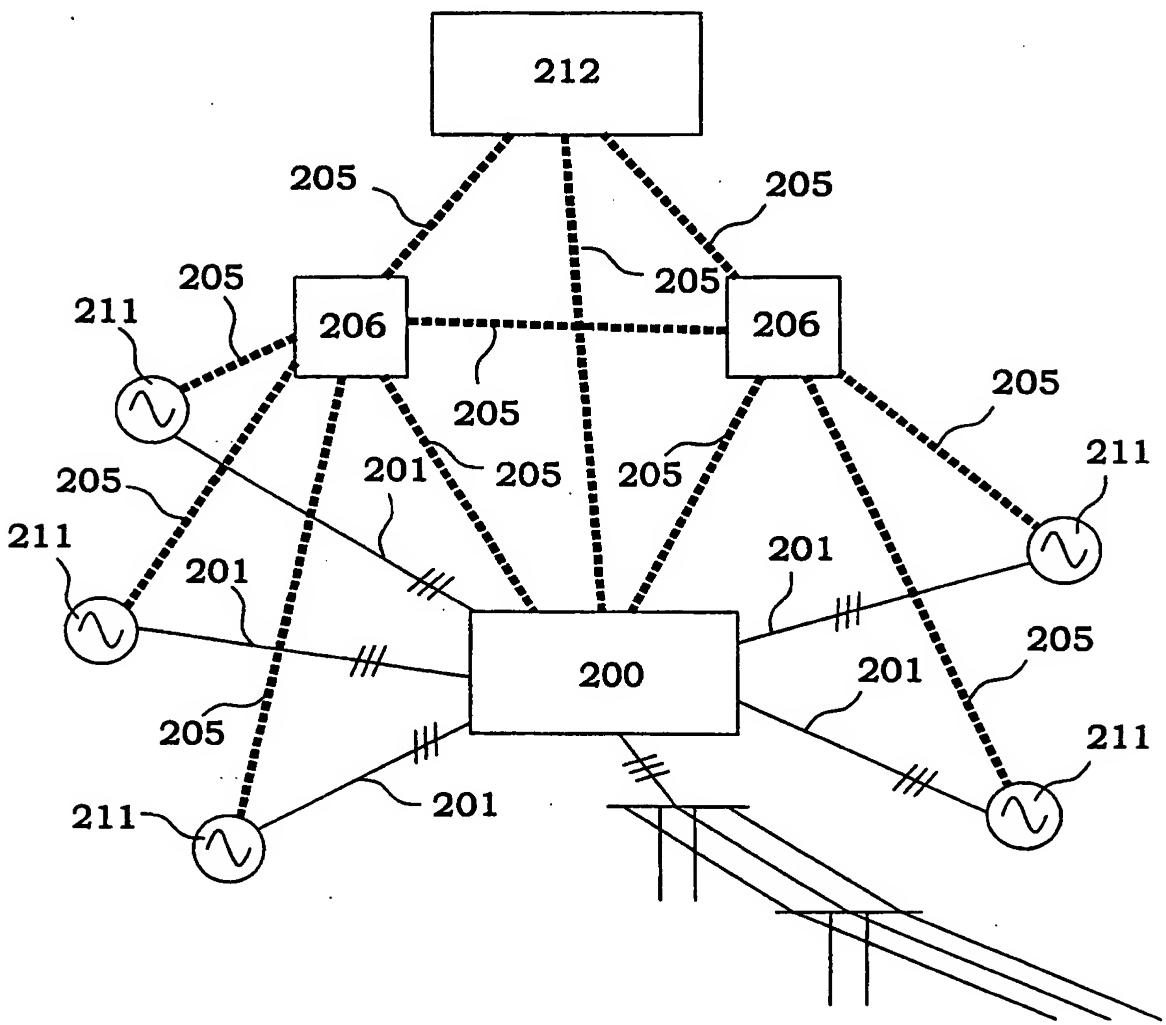

Fig. 14b

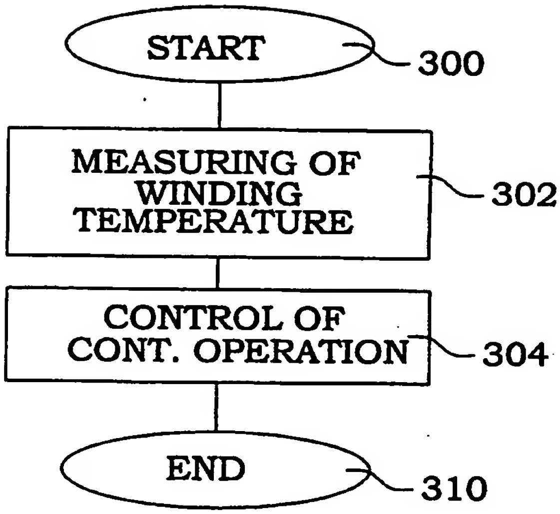

Fig. 15

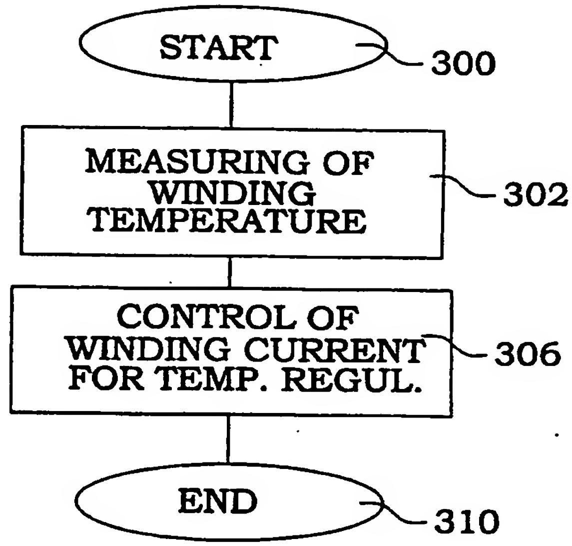

Fig. 16

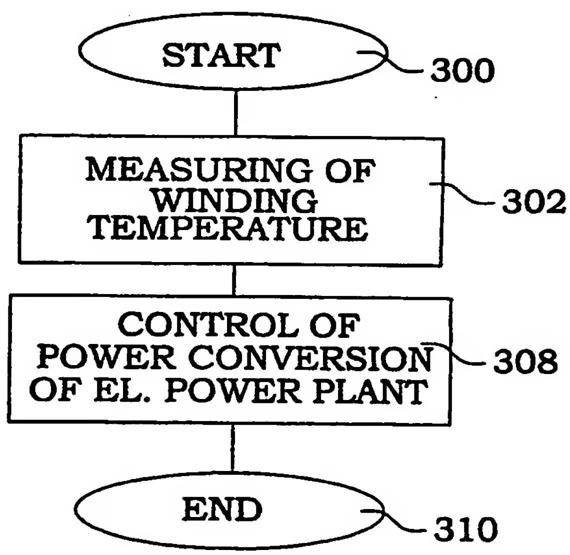

Fig. 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/01605

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H02H 7/06, H02P 9/10, H02K 19/00, G01K 7/00, G01K 13/08, H04B 7/00, H04L 5/00, H04L 12/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H02H, H02K, H02P, G01K, H04B, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SE 510315 C2 (ASEA BROWN BOVERI AB), 10 May 1999 (10.05.99), page 2, line 10 - line 13; page 4, line 4 - line 5; page 4, line 26 - line 35, pag 5,l 21-36; pag 6,l 1-11;pag 8, l 6-13; pag 9, l 12-13; pag 10, l 11-30; pag 12, l 19-34; pag 13, l 3-28; pag 14, l 3-9, l 13-18, l 20-36; abstract; see the whole document --	1-35
Y	US 4114077 A (ROBERT M. OATES ET AL), 12 Sept 1978 (12.09.78), column 1, line 39 - line 42; column 2, line 5 - line 39; column 4, line 20 - line 27, column 4, line 33-36; column 4, line 44-68; column 5, line 1-24 --	1-35

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 Sept 2000	30 -10- 2000
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Hans Bagge af Berga/LR Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/01605

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5321308 A (ALLAN W. JOHNCOCK), 14 June 1994 (14.06.94), column 2, line 38 - line 51; column 2, line 56 - line 59; column 4, line 58 - line 61, column 6, line 3-25, line 50-68;column 8, line 53-68; column 9, line 1-13; figure 1, abstract; --	1-35
A	EP 0902265 A1 (PFEIFFER VACUUM GMBH), 17 March 1999 (17.03.99), column 2, line 42 - line 54; column 3, line 3 - line 24, figure 1, abstract --	1-35
A	US 3876998 A (MARTIN RICHTER ET AL), 8 April 1975 (08.04.75), column 1, line 19 - line 50, abstract --	1-35
A	US 5257863 A (FRANK Y. CHU ET AL), 2 November 1993 (02.11.93), column 1, line 1 - line 10, abstract --	1-35
A	US 3824857 A (FOREST D. SMITH), 23 July 1974 (23.07.74), column 2, line 1 - line 14; column 3, line 12 - line 39, abstract -- --------	1-35